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Pre-distortion linearizing

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## Pre-distortion linearizing

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The present invention relates to a pre-distortion linearizing, in particular to a method, and an electronic device comprising a circuit for a pre-distortion linearizing.

The US 5,523,716 discloses a pre-distortion linearizer and a method for  
distorting an AC input branched signal to a power amplifier providing a distortion to the  
5 input branched signal which is complementary to a distortion in terms of gain and phase,  
introduced by the power amplifier as a function of branched signal amplitude, thereby to  
linearize the power amplifier. The linearizer includes a switching circuit having an input  
terminal and an output terminal and a pair of anti-parallel diodes connected between the input  
terminal and the output terminal of the switching circuit. The linearizer has also an impedance  
10 circuit comprising solely passive electrical elements connected between the input terminal  
and the output terminal of the switching circuit, wherein elements of the impedance circuit  
have values selected to introduce the complementary distortion to the input branched signal  
as a function of amplitude of the input branched signal to linearize the power amplifier.

The US 5,703,530 describes a radio-frequency amplifier circuit of simple  
15 construction having low power consumption and low heat generation and which amplifies an  
input branched signal while maintaining composite triple beat (CTB) distortion, type cross  
modulation distortion at a minimum. The radio-frequency amplifier comprises a transformer  
which transforms an input branched signal from an unbalanced state to a balanced state. The  
amplifier further comprises at least one distortion generation circuit including a first circuit  
20 having a nonlinear element and a first delay line coupled in series, and a second circuit  
having an attenuation element and a second delay line coupled in series. The first and second  
circuits are coupled in parallel. At least one distortion generation circuit is coupled to an  
input, an output, and/or an intermediate point of a radio-frequency amplification stage of the  
radio-frequency amplifier. The first and second delay lines are configured to create a delay  
25 time change in a branched signal input level of a branched signal input to the radio-frequency  
amplification stage which opposes a delay time change in the branched signal input level  
caused by a delay time difference between the input and output of the radio-frequency  
amplification stage. A transformer transforms the amplified input branched signal from the

balanced state back to an unbalanced state before outputting the amplified branched signal from the amplifier circuit.

The US 5,798,854 discloses an electronic circuit providing a linear output from a nonlinear transmission device such as a laser. Second and higher order distortion of the nonlinear device is compensated by applying a pre-distorted branched signal equal in magnitude and opposite in sign to the real and imaginary components of distortion produced by the nonlinear device. The input branched signal for the nonlinear device is applied to an in-line electrical path coupled to the nonlinear device. The in-line path contains at least one component for generating primarily real components of distortion. In some applications, at least one component for generating imaginary components of distortion is located on the in-line path. Filter stages are used to provide frequency dependent pre-distortion. In a preferred embodiment, an attenuator, a MMIC amplifier, a CATV hybrid amplifier, and a varactor in line with a semiconductor laser, provide the pre-distorted branched signal. In another embodiment, the real component of pre-distortion is generated by a FET configured as a voltage controlled resistor. In still another embodiment, the real component of pre-distortion is generated by the parallel combination of a diode and a resistor connected in series with the RF branched signal path. Also provided is a separate circuit including anti-parallel diodes and reactive elements for generating frequency dependent third-order pre-distortion.

The US 5,966,049 discloses a broadband linearizer for use with a power amplifier. The broadband linearizer includes a broadband linearizer bridge, a preamplifier/attenuator, a post amplifier/attenuator, and a control circuit. The broadband linearizer bridge includes a power divider and a power combiner interconnected by linear and nonlinear arms. The linear arm has a phase shifter, a passive equalizer, and a first delay line that are serially coupled together. The nonlinear arm has a distortion generator, an attenuator and a second delay line that are serially coupled together. A control circuit controls respective settings of the broadband linearizer bridge, preamplifier/attenuator and post amplifier/attenuator. The control circuit provides bias circuitry and sends command and telemetry branched signals to control operation of the broadband linearizer. The broadband linearizer provides for independent, flexible gain and phase control that can mate with different kinds of power amplifiers having various gain and phase performance.

The US 6,018,266 describes a radio frequency system including a reflective diode linearizer. The reflective diode linearizer has a quadrature hybrid circuit with an input, an output, a first tuned port, and a second tuned port. Each of the tuned ports has a reflection circuit in electrical communication. Each reflection circuit includes a first Schottky diode

having a cathode in electrical communication with the tuned port, a second Schottky diode having an anode in electrical communication with the tuned port, a first delay line having a first end in electrical communication with the tuned port, a second delay line having a first end in electrical communication with an anode of the first Schottky diode and also in  
5 electrical communication with a cathode of the second Schottky diode, and a radio frequency resistive element having a first end in electrical communication with a second end of the first delay line and a second end in electrical communication with a second end of the second delay line and with an electrical ground.

The US patents 5,523,716, US 5,703,530, US 5,798,854, and US 5,966,049  
10 suggest means for amplitude adjustment of the branched signal incident the input terminal of a distortion circuit and mean for amplitude adjustment of the branched signal outputted by an output terminal of the distortion circuit. The solutions of these patents make use of two main elements: conventional, single end or push-pull type, amplifiers; and distortion generation circuit made of two parallel branch-circuits including time delay and power  
15 dissipating components one of which is a non-linear impedance branch-circuit with non-linear device and another usually is a linear passive branch-circuit. The distortion generator circuits have several disadvantages, when used. They do not provide the isolation between branch-circuits so the tuning of one of the branch-circuit is effecting the performance/ delay time, impedance and transmission parameters/ of others parallel branch-circuits. They do not  
20 provide required rate of gain/phase expansion or AM/AM / AM/PM in case of deep saturation of one amplification stage or required characteristic of AM/AM and AM/PM vs input/output power in case of a multistage amplifier. Furthermore, they show high RF branched signal losses (more than - 15 dB), to achieve the required higher AM/PM and AM/AM regulation rate.

25 The US 6 018 266 describes a pre-distortion circuit where the key elements are the hybrid and diodes and where the main principle is a reflection of the branched signal from the diodes, connected to the hybrids ports, where the branched signal is going through the hybrid from the input port to the diodes and then reflected back to the other hybrids output port.

30 It is an object of the present invention to provide a method, and an electronic device comprising a circuit for a pre-distortion linearizing.

To achieve the object of the present invention, a method for a pre-distortion linearizing of a branched signal for a RF amplifier is disclosed, comprising supplying an input signal to at least one input terminal; distributing the input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals by a power  
5 distributing circuit; controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one nonlinear branch-circuit; controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one linear branch-circuit; combining output signals of at least one nonlinear branch circuit with the output signals of at least one linear branch by a power combining circuit; providing a final output signal of the  
10 pre-distortion unit from the power combining circuit on at least one output terminal. The method of the present invention increases the AM/AM and AM/PM expansion rate. That is enabled by using of parallel branches of linear and non-linear branches, wherein the parallel branches comprise an amplification element. The AM/AM rate and the AM/PM rate are separately controlled.

15 According to a preferred embodiment of the invention, the controlling of a phase parameter and/or an amplitude parameter of a branched signal by at least one nonlinear branch-circuit comprise controlling a phase of a branched signal by at least one phase control unit and/or; controlling an amplitude of a branched signal by at least one linear amplitude control unit and/or; controlling an amplitude of a branched signal by at least one nonlinear  
20 amplitude control unit. The AM/AM rate is controlled by the non-linear branch. This provides the possibility to control the AM/AM rate separate from the AM/PM rate.

According to a preferred embodiment of the invention, the controlling of a phase parameter and/or an amplitude parameter of a branched signal by at least one linear branch-circuit comprise controlling a phase variation of a branched signal by at least one  
25 phase control unit and/or; controlling an amplitude of a branched signal by at least one linear amplitude control unit. The linear branch controls the AM/PM rate separate from the AM/AM rate.

According to a preferred embodiment of the invention, the linear and/or the nonlinear amplitude control unit is controlled depending on a power level of an input signal.  
30 This advantageous feature enables that each branch starts with the regulation of its parameter depending on a power level of the input signal. This provides the possibility, that each branch is adapted to a special power level of the input signal.

According to a preferred embodiment of the invention, the linear and/or the nonlinear amplitude control unit is controlled depending on an external adjustable value. This

advantageous feature enables to adjust a value, from which the regulation of each branch depends.

According to a preferred embodiment of the invention, the linear and/or the nonlinear branch-circuit has its own specific RF power level from which its pre-distortion of amplitude and/or phase is starting, which is defined by an individual nonlinear function.

To achieve the object of the present invention, a method for a pre-distortion linearizing is disclosed, where the elements such as a varicap and a gain controlled amplifier can be used in particular for AM/AM and AM/PM temperature compensation of a linearized power module, comprising supplying an input signal to at least one input terminal;

distributing the input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals by a power distributing circuit; controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one nonlinear branch-circuit; controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one linear branch-circuit; combining output signals of at least one nonlinear branch circuit with the output signals of at least one linear branch by a power combining circuit; providing a final output signal of the pre-distortion unit from the power combining circuit on at least one output terminal.

To achieve the object of the present invention, an electronic device comprising a circuit for a pre-distortion unit linearizing a signal for a RF amplifier are disclosed, comprising at least one input terminal; a power distributing circuit distributing an input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals; at least one nonlinear branch-circuit controlling a phase parameter and/or an amplitude parameter of the branched signals; at least one linear branch-circuit controlling a phase parameter and/or an amplitude parameter of the branched signals; a power combining circuit combining output signals of at least one nonlinear branch circuit with the output signals of at least one linear branch circuit; at least one output terminal providing an output signal of the pre-distortion unit from the power combining circuit. The advantageous feature of the circuit and the layout is that the present invention cancels more than 20 dB of the third order inter-modulation. Minimizing of the third order inter-modulation is very important for wireless communication systems with digital modulation, such as WCDMA and EDGE. The circuit is very suitable for use in combination with a multistage power amplifier. The circuit can be used for a wide variety of power amplifiers, due to almost independent adjustability of AM/AM and AM/PM regulation rates and threshold power level. The circuit can be embodied in a semiconductor device, or as a circuit on a carrier such as a printed circuit

board. Preferably the electronic device is a module comprising a power amplifier and the circuit. Such module can for instance be used in portable communication devices, such as a mobile phone.

5 According to a preferred embodiment of the invention, the nonlinear branch-circuit comprise at least one phase control unit controlling the phase of a branched signal and/or; at least one linear amplitude control unit controlling the amplitude of a branched signal and/or; at least one nonlinear amplitude control unit controlling the amplitude of a branched signal. The advantageous feature of the one linear branch circuit is that the AM/AM rate is regulated separately from the AM/PM rate.

10 According to a preferred embodiment of the invention, the linear branch-circuit comprise at least one phase control unit controlling the phase of a branched signal and/or; at least one linear amplitude control unit controlling the amplitude of a branched signal.

According to a preferred embodiment of the invention, the nonlinear amplitude control unit comprise at least one nonlinear element; and at least one amplifier.  
15 The advantageous feature of the linear branch circuit is, that the AM/PM rate is regulated separately from the AM/AM rate.

According to a preferred embodiment of the invention, the nonlinear element is a diode.

20 According to a preferred embodiment of the invention, the nonlinear element is a circuit of anti-parallel connected diodes.

According to a preferred embodiment of the invention, a control backward biasing unit is connected to the circuit of anti-parallel connected diodes.

According to a preferred embodiment of the invention, the nonlinear element is a transistor.

25 According to a preferred embodiment of the invention, the amplifier is a gain control amplifier.

According to a preferred embodiment of the invention, the amplifier has its own amplifier class.

30 According to a preferred embodiment of the invention, the amplifier is an A- or AB- or B- or C- or E- or F-class amplifier.

According to a preferred embodiment of the invention, the linear amplitude control unit is a gain control amplifier and/or an attenuator and/or a resistor and/or a dissipative transmission line and/or a controllable resistive component.



According to a preferred embodiment of the invention, the amplifier has its own amplifier class.

According to a preferred embodiment of the invention, the amplifier is an A- or AB- or C- or E- or F-class amplifier.

5           According to a preferred embodiment of the invention, the amplifier comprise at least one transistor.

According to a preferred embodiment of the invention, the phase control unit comprises at least one transmission line.

10          According to a preferred embodiment of the invention, the transmission lines are connected in parallel and/or in serial.

According to a preferred embodiment of the invention, the transmission line is a quarter-wave-length transmission line.

According to a preferred embodiment of the invention, the transmission line is artificial and/or distributed.

15          According to a preferred embodiment of the invention, the transmission line is an impedance transformation circuit and/or a filtering circuit and/or a phase shifter circuit.

According to a preferred embodiment of the invention, the transmission line comprise a serial and/or a parallel circuit of at least one resistor and/or capacitance and/or inductance.

20          According to a preferred embodiment of the invention, the phase control unit comprise at least one, controlled resistive element.

According to a preferred embodiment of the invention, the controlled resistive element is connected between ground and a connection point of at least two transmission lines.

25          According to a preferred embodiment of the invention, the controlled resistive element is connected between ground and at least one terminal of the amplifier of the linear amplitude control unit and/or the nonlinear amplitude control unit.

30          According to a preferred embodiment of the invention, a controlling input of the controlled resistive element is connected to at least one terminal of the amplifier of the linear amplitude control unit and/or the nonlinear amplitude control unit.

According to a preferred embodiment of the invention, the linear and/or the nonlinear branch-circuit has a filtering circuit at an output terminal.

According to a preferred embodiment of the invention, the filtering circuit is a low pass filter or a high pass filter.

According to a preferred embodiment of the invention, the filtering circuit comprise a serial and/or a parallel circuit of at least one resistor and/or at least one capacitance and/or at least one inductance.

According to a preferred embodiment of the invention, the circuit is integrated  
5 in a semiconductor circuit.

According to a preferred embodiment of the invention, the circuit is implemented in a MMIC circuit technology.

These and various other advantages and features of novelty which characterize the present invention are pointed out with particularity in the claims annexed hereto and  
10 forming a part hereof. However, for a better understanding of the invention, its advantages, and the object obtained by its use, reference should be made to the drawings which form a further part hereof, and to the accompanying descriptive matter in which there are illustrated and described preferred embodiments of the present invention.

15

Figure 1 shows a basic block schematic of the pre-distortion linearizer of the present invention;

Figures 2 to 6 show a circuit diagram and graphs of an embodiment of the present invention;

20

Figures 7 to 16 show another embodiment of the present invention with the related circuit diagram and the related measured graphs;

Figures 17 to 27 show different embodiments of the present invention.

25

Figure 1 shows a basic block schematic of the present invention of a pre-distortion linearizer. Equivalent parts have equivalent numbers. This is done in the whole description of the present invention. The basic block schematic of Figure 1 comprises an input terminal 2 connected to a power distribution circuit 4. The power distribution circuit 4 is connected to the parallel branches 16, 18 and 20. Branch 16 represents the first linear  
30 branch, branch 18 represents the first non-linear branch, and branch 20 represents the  $n^{\text{th}}$  non-linear branch. The branch 16 comprises a phase control unit 6, also called transmission line unit, connected on the one side to the power distribution circuit 4 and on the other side to a linear amplitude control unit 8. The linear amplitude control unit 8 is connected on the other

side to another phase control unit 6. The phase control unit 6 is connected on the other side to a power combiner circuit 12.

The branch 18 is connected in parallel to the branch 16 between the power distribution circuit 4 and the power combiner circuit 12. The branch 18 comprise a serial circuit of a non-linear amplitude control unit 10 connected on the one side to the power distribution circuit 4 and on the other side connected to a linear amplitude control unit 8. The a linear amplitude control unit 8 is connected on the other side to phase control unit 6. The phase control unit 6 connected on the other side to the power combiner circuit 12.

The branch 20 is the n-branch of this block schematic. The branch 20 is in parallel to the branches 16 and 18 connected between the power distribution circuit 4 and the power combiner circuit 12. The branch 20 comprises a serial circuit comprising a non-linear amplitude control unit 10 connected on the one side to the power distribution circuit 4 and on the other side connected to a linear amplitude control unit 8. The a linear amplitude control unit 8 is connected on the other side to a phase control unit 6. The phase control unit 6 connected on the other side to the power combiner circuit 12. to a phase control unit 6. The phase control unit 6 is connected on the other side to the power combiner circuit 12. The power combiner circuit 12 is connected to the output terminal 14.

The pre-distortion unit of the embodiments of the invention include several parallel branches which generate a pre-distortion signal at different level of input power, while providing also a different pre-distortion rate, provides a better compensation of gradually changing rate of AM/AM and AM/PM in the power amplifier.

Figure 2 shows a possible embodiment of the present invention. The embodiment comprises an input terminal 30 connected to the capacitances 32 and 68. The other side of the capacitance 32 is connected to an anode of diode 34 and to a cathode of diode 38. The cathode of diode 34 is connected to a resistor 44, a resistor 46 and a capacitance 36. The other side of resistor 44 is connected to terminal 42. The anode of diode 38 is connected to the other side of resistor 46, to a capacitance 40, and to a resistor 48. The other side of the resistor 48 is connected to ground. The other side of the capacitance 40 is connected to the other side of capacitance 36 and to a resistor 50, a basis terminal of transistor 62, a resistor 52, and a capacitance 54. The other side of the resistor 52 is connected to terminal 60. The other side of resistor 50 is connected to ground. The other side of the capacitance 54 is connected to a resistor 56. The other side of the resistor 56 is connected to a resistor 58 and a collector terminal of transistor 62. The other side of the

resistance 58 is connected to terminal 60. The collector terminal of transistor 62 is connected to the resistors 56, 58 and a capacitance 64.

An emitter of the transistor 62 is connected to a adjustable resistance 66. The other side of the resistor 66 is connected to ground. The other side of the capacitance 64 is connected to an output terminal 88. The other side of the capacitance 68 is connected to a delay line 70, which is adjustable. The other side of the delay line 70 is connected to a resistor 74, a resistor 72, a capacitance 76, and a basis terminal of transistor 84. The other side of the resistor 74 is connected to ground. The other side of the resistor 72 is connected to a terminal 80. The other side of the capacitance 76 is connected to a resistor 78. The other side of the resistor 78 is connected to a resistor 82, a capacitance 90, and a collector terminal of the transistor 84. The other side of the capacitance 90 is connected to the output terminal 88. The emitter terminal of the transistor 84 is connected to a resistor 86. The other side of the resistor 86 is connected to ground.

This embodiment comprises for simplicity reasons only two branches. There are a non-linear branch and a linear branch. The non-linear branch is the upper branch shown in Figure 2 with a threshold regulation circuit comprising the elements 34 to 48 and an amplifier stage comprising the elements 50 to 66. The linear branch comprises a delay line 70 of any type and a linear amplifier stage comprising the elements 72 to 86.

The amplifier stage of the transistor 62 provides the gain, which compensates the signal losses in the threshold control circuit, which is created by the diodes 34 and 38. The gain of the amplifier stage is defined by the values of the feedback resistors 56 and 66 and may achieve an attenuation value of (1...10)dB. When tuning the value of the resistor 66 in the emitter of transistor 62 from 0 to 4 Ohm, the gain of the amplifier stage varies from 4 to 10 dB, providing an almost independent AM/AM rate regulation, where the AM/PM rate is constant versus the resistor 66, which is shown in the Figures 3 and 4.

The amplifier stage in the linear branch has lower gain and is advantageous for providing good isolation of the delay line from the non-linear branch and regulation of the initial value of the transmission coefficient of the pre-distortion unit of this embodiment.

Providing additional non-linear parallel branches, the required AM/AM and AM/PM characteristic shapes can be achieved in this embodiment without degradation of the original parameters, due to the properties of the amplifiers to isolate the output of every branch from others, provided that the parameter S12 of the amplifier is less than -10 dB.

To summarize, the specific embodiment of the present invention described above comprises a linear branch and at least one non-linear branch, which is in parallel to the

linear branch. The non-linear branch comprises an amplifier stage of an amplifier in A-class and a threshold power control unit with independent biasing. The non-linear branch controls the AM/AM rate. The linear branch comprise also an amplifier stage and a control unit with controlled bias in the linear branch. The control, unit for example a delay line, controls the AM/PM rate. The amplifier stage comprises an amplifier in A-class. The linear branch controls the AM/PM rate.

In the embodiment of the present invention described above, there is an amplification element inside the parallel branches which in fact radically increases the AM/AM and AM/PM expansion rate and provides the isolation between the said parallel branches outputs when combined, which helps for independent tuning and adjustment of the said parallel branches parameters.

The embodiment of the present invention described above gives also a solution for controlling of the threshold power level, such as anti-parallel diodes with independent biasing, whereby in this embodiment terminal 42 and an A-class amplifier, or a B-/C-class amplifier with controlled bias in one independent non-linear branch, the threshold level, the input power level, above which the amplitude and phase transfer characteristics of the pre-distortion unit are starting to be changed, can be adjusted by one controlling signal through one special port.

In the shown embodiment of Figure 2 the AM/AM rate is controlled via the adjustable resistor 66 and the AM/PM rate is controlled via the adjustable delay line 70. Figures 3 and 4 show measured lines at independent AM/AM regulation at constant AM/PM rate in the pre-distortion unit embodiment of Figure 1. The graphs show different values of the resistor 66. The graph 100 represents the value of 0 Ohm of the resistor 66. The graph 102 represents the value of 1 Ohm of the resistor 66. The graph 104 represents the value of 2 Ohm of the resistor 66. The graph 106 represents the value of 3 Ohm of the resistor 66. The graph 108 represents the value of 4 Ohm of the resistor 66.

Figures 5 and 6 show independent AM/PM regulation at constant AM/AM rate in the pre-distortion unit embodiment of Figure 2. In Figure 5 the graph 110 represents 30°. The graph 112 represents 40°. The graph 114 represents 50°. The graph 116 represents 60°. The graph 118 represents 80°. The graph 120 represents 90°. In Figure 6, the graph 122 represents 30°. The graph 124 represents 40°. The graph 126 represents 50°. The graph 128 represents 60°. The graph 130 represents 70°. The graph 132 represents 80°.

Figure 7 shows another embodiment of the present invention. The shown embodiment comprises an input terminal 140 connected to a capacitance 142. The

capacitance 142 is connected on the other side to the anode of a diode 158, the cathode of a diode 160 and a capacitance 144. The capacitance 144 is connected on the other side to a delay line 146. The delay line 146 is connected on the other side to a resistance 148. The resistance 148 is connected on the other side to a capacitance 150 and a resistance 152. The capacitance 150 is connected on the other side to ground. The resistance 152 is connected on the other side to an output terminal 172. The cathode of the diode 158 is connected to an inductance 156, a capacitance 166 and a resistor 162. The other side of the resistor 162 is connected to the anode of the diode 160, an inductance 164 and a capacitance 168. The inductance 164 is connected to ground. The other side of the capacitance 168 is connected to another side of the capacitance 166 and an amplifier 170. The amplifier 170 is connected to the output terminal 172. The terminal 154 of the threshold power control is connected to the other side of the inductance 156.

The amplifier 170 is an amplifier with gain control. The capacitance 150 is a variable capacitance or an element with controlled capacitance value. The embodiment is a pre-distortion unit with extended dynamic range and controllable AM/AM and AM/PM regulation rates. It has been shown that the amplifier 170, when gain varies from 0 dB to 6 dB, provides simultaneously phase valuation rate control from  $5^\circ/\text{dB}$  to  $20^\circ/\text{dB}$  and an amplitude regulation rate control from 0.3 dB/dB to 1 dB/dB. Furthermore, the variation of the capacitance 150 from 0 to 3 pF can provide AM/AM regulation rate control, while the AM/PM rate characteristic is constant. The IRL of the pre-distortion unit is less than -10 dB in the power range. The initial losses also can be improved to about -3 dB instead of -(8...6) dB.

The pre-distortion unit of the embodiments of the present invention provides an extended dynamic range, a control over a threshold input power level at which the amplitude and phase regulation begins, an independent control over amplitude and phase regulation rates in the range of a pre-distortion, and a higher amplitude and phase regulation rate.

This pre-distortion unit can also be used at the same time for temperature compensation of linearized power module, where a VARICAP, presented as a capacitance 150, is a controlled element of AM/AM compensation loop and an amplifier controlling element for an AM/PM compensation.

The Figures 8 to 16 show different measurements of the embodiment of Figure 7. Figures 8, 9 and 10 represent AM/AM and AM/PM and IRL versus different values of bias voltage. Figures 11 and 12 show AM/AM and AM/PM regulation rate of the pre-distortion

unit versus different values of the capacitance 150. Figure 13 shows the effect of the different values of the capacitance 150 on IRL of the pre-distortion unit of Figure 7. Figures 14 and 15 show the AM/AM and the AM/PM regulation rate of the pre-distortion unit versus the gain of the amplifier. Figure 16 shows the effect of the amplifier gain on IRL of the pre-distortion unit.

Further embodiments of the present invention are presented in Figures 17 to 27. In order to show the principle and for reasons of simplicity, only the first and second branches are shown.

Figure 17 shows an embodiment of the present invention. The embodiment comprises an input terminal 180 connected to a capacitance 182 and to a capacitance 202. The other side of the capacitance 182 is connected to an anode of the diode 184 and to a cathode of the diode 188. The anode of the diode 184 is connected to a capacitance 186, a resistor 194 and a resistor 196. The resistor 194 is connected on the other side to a terminal 192. The capacitance 186 is connected on the other side to an input terminal of an amplifier 200 and a capacitance 190. The other side of the resistor 196 is connected to the other side of the capacitance 190, a resistor 198 and the anode of the diode 188. The other side of the resistor 198 is connected to ground. The amplifier 200 is connected to a gain control unit 201. The upper terminal of the amplifier 200 is connected to the output terminal 212. The other side of the capacitance 202 is connected to a delay line 204. The other side of the delay line 204 is connected to a resistor 206. The other side of the resistor 206 is connected to an adjustable capacitance 208 and to a resistor 210. The other side of the capacitance 208 is connected to ground. The other side of the resistor 210 is connected to the output terminal 212.

The described embodiment includes an amplification block (so-called gain control amplifier-AGC) which helps for low losses of the pre-distortion unit and higher achievable rates of the phase and amplitude pre-distortions.

The elements 184 to 198 provide a threshold control of the input signal. The terminal 192 provides the bias voltage of the threshold control unit. Furthermore, the threshold control unit of the elements 184 to 198 and the amplifier 200 form the non-linear branch. The linear branch is formed by the delay line 204 and the resistors 206 and 210 and the adjustable capacitance 208. The adjustable capacitance 208 serves for controlling the AM/PM rate.

Figure 18 shows another embodiment of the present invention. The embodiment comprise an input terminal 214 connected to a capacitance 216 and to a

capacitance 238. The capacitance 216 is connected on the other side to a threshold control unit, which is equivalent to the before described threshold control unit of Figure 17.

Therefore the elements 218 to 232 are equivalent to the elements 184 to 198 of Figure 17.

The capacitances 220 and 224 are connected to a delay line 234. The delay line is connected  
5 on the other side to an amplifier 236 which is a gain control amplifier. The output of the amplifier 236 is connected to the output terminal 246. The other side of the capacitance 238 is connected to a resistor 240. The other side of the resistor 240 is connected to an input terminal of an amplifier 242. The amplifier 242 is also a gain control amplifier.

The output terminal of the amplifier 242 is connected to a delay line 244. The  
10 output of the delay line 244 is connected to the output terminal 246. In this embodiment both branches have a gain control amplifier. These gain control amplifiers 236 and 242 can provide separate amplitude and phase pre-distortion rate adjustment without gain losses. The upper branch of Figure 18 is the non-linear branch providing the AM/AM rate regulation, and the lower branch of Figure 18 provides the AM/PM rate regulation.

15 Figure 19 shows another embodiment of the present invention. This embodiment comprises an input terminal 250 connected to a capacitance 252 and to a capacitance 262. The other side of the capacitance 252 is connected to a resistor 254. The other side of the resistor 254 is connected to a delay line 256. The other side of the delay line 256 is connected to an amplifier 258. The amplifier 258 is a B-class amplifier. The amplifier  
20 258 is connected to a bias control unit 260. The output terminal of the amplifier 258 is connected to an output terminal 270. The other side of the capacitance 262 is connected to a resistor 264. The other side of the resistor 264 is connected to an amplifier 266. The amplifier 266 is a gain control amplifier. The output terminal of the amplifier 266 is connected to a delay line 268. The other side of the delay line is connected to the output terminal 270.

25 The shown embodiment has the following features. The delay lines 256 and 268 specify for the required phase the pre-distortion rate. The gain of the amplifier 266 defines the pre-distortion unit gain. The amplifier 258 connected to the bias control unit 260 defines a threshold power level adjustment. An amplitude pre-distortion rate is defined by the ratio between re-gain of the amplifier 266 and the gain of the amplifier 258. The resistors 254  
30 and 264 are used for power division and matching conditions.

The embodiment of Figure 20 comprises an input terminal 272 connected to a power divider 274. The power divider 274 is connected to one side of a delay line 276 and to an input terminal of an amplifier 280. The amplifier 280 is a gain control amplifier. The other side of the delay line 276 is connected to an input terminal of an amplifier 278. The amplifier



278 is a B-class amplifier. The amplifier 278 is connected to a bias control unit which is not shown. The output of the amplifier 278 is connected to an output terminal 284. The output terminal of the amplifier 280 is connected to one side of a delay line 282. The other side of the delay line 282 is connected to the output terminal 284.

5           The difference of the embodiment shown in Figure 20 and the former embodiments is that that the embodiment of Figure 20 comprises a power divider 274 at the input. This power divider 274 can provide better and constant input return losses.

          The embodiment of Figure 21 comprise an input terminal 290 connected to a hybrid coppler 294. A resistance 292 of 50 OHM is connected on the one side to the hybrid  
10   coppler 294. The other side of the resistance 292 is connected to ground. The hybrid coppler 294 crosses the lines from the resistor 292 to an A-class amplifier 298 with the line of the input terminal 290 to an amplifier 296. Therefore the input terminal 290 is connected directly via the hybrid coppler 294 to the amplifier 296. Also the resistance 292 is connected directly via the hybrid coppler 294 to an input terminal of the amplifier 298. The amplifier 298 is a  
15   gain control amplifier. The output terminal of the amplifier 298 is connected to one side of a delay line 300. The delay line 300 is adjustable. The other side of the delay line 300 is connected to an output terminal 302. The amplifier 296 is a B-class amplifier connected to a bias control unit. The output terminal of the amplifier 296 is connected to the output terminal 302.

20           As the embodiment shown in Figure 20, the embodiment of Figure 21 also differs from the preceding embodiments in that the embodiment of Figure 21 comprises a power divider at the pre-distortion unit input. This power divider in Figure 21 is represented by the hybrid coupler 294. This hybrid coupler 294 provides better and constant input return losses.

25           Figure 22 shows an embodiment of the present invention comprising an input terminal connected to a power divider 314. A resistance 312 is connected on one side to ground and on the other side the resistor is connected to the power divider 314. The power divider 314 crosses the lines from the input terminal 310 to a 90° delay line 324 with the line from the resistor 312 to a delay line 316. The delay line 316 is connected on the other side to  
30   a gate terminal of a transistor 318. The transistor 318 is a B-class amplifier. The drain terminal of transistor 318 is connected to a power supply which is not shown. The drain terminal of transistor 318 is also connected to an output terminal 330. The source terminal of transistor 318 is connected to a resistor 320 and a capacitance 322. The resistor 320 and the capacitance 322 are connected on the other side to ground. The other side of the delay line

324 is connected to a 90° delay line 328 and a drain terminal of a transistor 326. The transistor 326 represents a controllable electrical resistance element. The source terminal of transistor 326 is connected to ground. The gate terminal of transistor 326 is connected to the source terminal of transistor 318. The other side of the delay line 328 is connected to the output terminal 330.

The circuit of Figure 22 uses a property of 90° transmission or delay lines 324 and 328 as an impedance inverter where after the passing of the threshold power level in the B-class amplifier 318, the drain or collector current appears and starts to grow and the voltage to drop, and the resistor 320 acting as a drain or collector current sensor is opening the transistor 326 as a controllable resistance element which provides finally a short circuit in the point of 90° lines connection which is the connection point between the 90° delay line 324 and the 90° delay line 328 and an open circuit at the opposite sides of the delay lines 324, 328. Thus, the RF-signal is switched from one branch to another, providing constant input/output impedance of the pre-distortion unit circuit.

Another simplified configuration of the circuit of Figure 22 is shown in Figure 23. The circuit of Figure 23 comprises an input terminal 340 connected to a gate terminal of a transistor 342 and connected to a delay line 348. The transistor 342 is a B-class amplifier. The drain terminal of transistor 342 is connected to a power supply which is not shown and to an output terminal 354. The source terminal of transistor 342 is connected to a resistor 344 acting as a drain or collector current sensor and a capacitance 346. The resistor 344 and the capacitance 346 are connected to ground. The other side of the delay line 348 is connected to a delay line 350 and to a drain terminal of a transistor 352. The transistor 352 is a controllable electrical resistive element. The source terminal of the transistor 352 is connected to ground. The gate terminal of transistor 352 is connected to the source terminal of transistor 342.

Figure 24 shows an embodiment of the present invention comprising an input terminal connected to a resistance 362 and to a resistance 368. The other side of the resistance 362 is connected to a capacitance 364. The other side of the capacitance 364 is connected to a gate terminal of a transistor 366. The transistor 366 is a B-class amplifier. A bias control unit of threshold power 365 is connected to the gate terminal of the transistor 366. A not shown power supply is connected to a drain terminal of transistor 366. A source terminal of transistor 366 is connected to ground. The drain terminal of transistor 366 is connected to an output terminal 378. The other side of the resistor 368 is connected to a capacitance 370. The other side of the capacitance 370 is connected to a delay line 372. The

other side of the delay line 372 is connected to an adjustable capacitance 374 and to an input terminal of the amplifier 376. The capacitance 374 is used to control the AM/PM rate. The amplifier 376 is a gain control amplifier, allowing to adjust the losses of the branch and isolation between the branches. The amplifier 366 is used to control the AM/AM rate. The output terminal of the amplifier 376 is connected to the output terminal 378.

Figure 25 shows another embodiment of the present invention. The circuit of Figure 25 comprises an input terminal 380 connected to a capacitance 382 and a capacitance 391. The capacitance 382 is connected on the other side to a resistance 384. The resistance 384 is connected on the other side to an input terminal of an amplifier 386. The amplifier 386 is a B-class amplifier. The output terminal of amplifier 386 is connected to an output terminal 398. The amplifier 386 is connected via a control terminal to a resistor 390 and a capacitance 388. The resistor 390 and the capacitance 388 are connected on the other side to ground. The other side of the capacitance 391 is connected to a resistance 392. The other side of the resistance 392 is connected to an input terminal of an amplifier 394. The amplifier 394 is a gain control amplifier. The output terminal of the amplifier 394 is connected to a delay line 396. The delay line 396 is connected to the output terminal 398. A gain control terminal of the amplifier 394 is connected to the resistor 390 and to the capacitance 388.

Figure 26 shows another embodiment of the present invention. The embodiment comprises an input terminal 400 connected to a capacitance 402 and a delay line 424. The capacitance 402 is connected to a resistance 404. The other side of the resistance 404 is connected to a resistance 406, a capacitance 408, a gate terminal of a transistor 414 and a resistance 416. The resistance 416 is connected on the other side to ground. The resistor 406 is connected on the other side to a control voltage  $V_c$ . The voltage  $V_c$  controls the threshold voltage. The capacitance 408 is connected to a resistance 410. The resistance 410 is on the other side connected to an inductance 412 and to a drain terminal of the transistor 414. The inductance 412 is connected on the other side to the control voltage  $V_c$ . The drain terminal of transistor 414 is connected to a capacitance 418. The source terminal of transistor 414 is connected to a resistance 420 and to a capacitance 422. The resistance 420 and the capacitance 422 are connected on the other side to ground. The other side of the delay line 424 is connected to a capacitance 426. The other side of the capacitance 426 is connected to the other side of the capacitance 418 and to an output terminal 428. The transistor 414 is a B-class amplifier. The resistance 420 is used to control the AM and the PM rate.

The embodiment of Figure 27 comprises an input terminal 430 connected to a capacitance 432 and to a resistance 458. The capacitance 432 is connected to a resistance

434. The other side of the resistance 434 is connected to a resistance 436, a capacitance 438, a gate terminal of a transistor 448 and a resistor 450. The resistor 450 is connected on the other side to ground. The resistor 436 is connected on the other side to a terminal 444 which provides a threshold control signal. The capacitance 438 is connected on the other side to a resistor 440. The resistor 440 is connected on the other side to a resistor 442, a drain terminal of transistor 448 and to a capacitance 452. The other side of the resistance 442 is connected to a terminal 446 providing a supply voltage. The other side of the capacitance 452 is connected to an output terminal 484. A source terminal of transistor 448 is connected to a resistance 454 and to a capacitance 456. The other side of the resistance 454 and the capacitance 456 is connected to ground. The other side of the resistance 458 is connected to a capacitance 460 and to a resistance 462. The other side of the capacitance 460 is connected to ground. The other side of the resistance 462 is connected to a resistance 464, a capacitance 466, a gate terminal of a transistor 476, a resistance 478 and to a drain terminal of a transistor 480. The other side of the resistor 478 is connected to ground. The other side of the resistance 464 is connected to a terminal 472. The terminal 472 provides a threshold control signal. The other side of the capacitance 466 is connected to a resistance 468. The resistance 468 is connected on the other side to a resistance 470, a drain terminal of the transistor 476 and to a capacitance 482. The other side of the resistance 470 is connected to a terminal 474 providing a supply voltage. The source terminal of transistor 476 is connected to ground. A source terminal of transistor 480 is connected to ground. A gate terminal of transistor 480 is connected to the resistor 454 and to the capacitance 456. The other side of the capacitance 482 is connected to the output terminal 484. The transistor 448 is a B-class amplifier. The resistance 454 is a drain current sensor. The transistor 476 is an A-class amplifier.

The embodiments of the present invention provide an amplification element inside the parallel branch-circuits, which radically increases the AM/AM and AM/PM expansion rate and provides the isolation between the said parallel branch-circuits outputs when combined, which helps for independent tuning and adjustment of the said parallel branch-circuits parameters. The embodiments of the present invention provide also a solution for controlling of the threshold power level, such as anti-parallel diodes with independent biasing and a A-class amplifier, or B/C-class amplifier with controlled bias in one independent non-linear branch-circuit, where the threshold level, the input power level, above which the amplitude and phase transfer characteristics of the pre-distortion unit are starting to be changed, can be adjusted by one controlling branched signal through one special port.

The embodiments of the present invention provide an additional port for the threshold regulation; an amplifier, A- and B-Class, which significantly improves AM/AM regulation rate, which is particularly important for the multistage power amplifier compensation; introduction of more than one non-linear branch-circuit; the embodiments of the present invention are not limited to the only microwave circuitry; the non linear elements are is not limited to just Schottky and PIN diodes, but include also other circuit elements such as transistors as a resistive element; and introduction of filters, for harmonic level control.

An ideal pre-distortion linearizer can be applied together with different power amplifiers; i.e. it need not to be adapted if one power amplifier is replaced by another power amplifier. The proposed solution to realize this, is the use of a linearizer with at least two parallel branch-circuits, at least one linear, the others non-linear, the non-linear branch-circuit comprises an impedance and an amplifier, the linear branch-circuit comprises an impedance and optionally an amplifier. The nonlinear branch-circuit can be split into a plurality of non-linear branch-circuits.

The amplifier of the linearizer has the following functions. It is operated as a diode, to block a reflection of the branched signal at an eventual mismatch between the variable output resistance of the linear circuit and the non-variable resistance of the switch thereafter; generating a harmonic signal that is opposed to the harmonic signal of the power amplifier; provision of a modification of the branched signal of certain traps within the power amplifier, which modification is in phase with the branched signal. Usually the branched signals are somewhat out of phase, leading to a smoothening of the gain curve due to saturation effects. This is particularly of importance if various non-linear circuits are provided. Due to the presence of the amplifier in the linearizer, the circuits can be adapted independently of each other. The use of amplifiers is further on advantageous, since they can be integrated easily (instead of the diodes), therewith reducing the amount of assembly. The parallel placements of the circuits has the function that phase and amplitude are separated.

The linearizer cancels more than 20 dB of the third order inter-modulation. This third order inter-modulation is very important for wider bands, such as wideband CDMA and EDGE. The linearizer is very suitable for use in combination with a multistage power amplifier. The linearizer can be used for a variety of power amplifiers due to relatively independent adjustability of the three key parameters such as AM/AM, AM/PM and threshold power .

New characteristics and advantages of the invention covered by this document have been set forth in the foregoing description. It will be understood, however, that this

disclosure is, in many respects, only illustrative. Changes may be made in details, particularly in matters of shape, size, and arrangement of parts, without exceeding the scope of the invention. The scope of the invention is, of course, defined in the language in which the appended claims are expressed.

## CLAIMS:

EPO - DG 1

22 10 2002

(71)

1. A method for a pre-distortion linearizing a branched signal for a RF amplifier, comprising

supplying an input signal to at least one input terminal;

5 distributing the input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals by a power distributing circuit;

controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one nonlinear branch-circuit;

controlling a phase parameter and an amplitude parameter of the branched signals by at least one linear branch-circuit;

10 combining output signals of at least one nonlinear branch circuit with the output signals of at least one linear branch circuit by a power combining circuit;

providing an final output signal of the pre-distortion unit from the power combining circuit on at least one output terminal.

15 2. The method of claim 1, wherein the controlling of a phase parameter and/or an amplitude parameter of the branched signal by at least one nonlinear branch-circuit comprise controlling a phase of a branched signal by at least one phase control unit and/or;

controlling an amplitude of a branched signal by at least one linear amplitude control unit and/or;

20 controlling an amplitude of a branched signal by at least one nonlinear amplitude control unit.

3. The method of claim 1, wherein the controlling of a phase parameter and/or an amplitude parameter of a branched signal by at least one linear branch-circuit comprise controlling a phase variation of a branched signal by at least one phase control unit and/or;

controlling an amplitude of a branched signal by at least one linear amplitude control unit.

4. The method of claim 2, wherein the linear amplitude control unit and/or the nonlinear amplitude control unit are/is controlled depending on a power level of an input signal.

5

5. The method of claim 2 or 3, wherein the linear amplitude control unit and/or the nonlinear amplitude control unit are/is controlled depending on an external adjustable value.

10

6. The method of claim 1, wherein the linear amplitude control unit and/or the nonlinear branch-circuit have their/its own specific RF power level from which their/its pre-distortion of amplitude and/or phase is starting, which is defined by an individual nonlinear function.

15

7. A method for a pre-distortion linearizing, in particular compensating temperature of a linearized power module, where a varicap is a controlled element of a AM/AM compensation loop and a amplifier controlling element for AM/PM compensation, comprising

supplying an input signal to at least one input terminal;

20

distributing the input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals by a power distributing circuit;

controlling a phase parameter and/or an amplitude parameter of the branched signals by at least one nonlinear branch-circuit;

controlling a phase parameter and/or an amplitude parameter of the branched

25

signals by at least one linear branch-circuit;

combining output signal of at least one nonlinear branch circuit with the output signal of at least one linear branch circuit by a power combining circuit;

providing a final output signal of the pre-distortion unit from the power combining circuit on at least one output terminal.

30

8. An electronic device comprising a circuit for a pre-distortion unit linearizing a signal for a RF amplifier, comprising

at least one input terminal supplying an input signal;



a power distributing circuit distributing the input signal present on at least one input terminal to a plurality of parallel branch-circuits as branched signals;

at least one nonlinear branch-circuit controlling a phase parameter and/or an amplitude parameter of the branched signals;

5           at least one linear branch-circuit controlling a phase parameter and/or an amplitude parameter of the branched signals;

a power combining circuit combining output signals of at least one nonlinear branch circuit with the output signals of at least one linear branch circuit;

10           at least one output terminal providing an output signal of the pre-distortion unit from the power combining circuit.

9.           The device of claim 8, wherein the nonlinear branch-circuit comprise at least one phase control unit controlling the phase of a branched signal and/or;

15           at least one linear amplitude control unit controlling the amplitude of a branched signal and/or;

at least one nonlinear amplitude control unit controlling the amplitude of a branched signal.

20   10.       The device of claim 8, wherein the linear branch-circuit comprise at least one phase control unit controlling the phase of a branched signal and/or;

at least one linear amplitude control unit controlling the amplitude of a branched signal.

25

11.       The device of claim 9, wherein the nonlinear amplitude control unit comprises at least one nonlinear element; and at least one amplifier.

12.       The device of claim 10, wherein the linear amplitude control unit is a gain control amplifier and/or an attenuator and/or a resistor and/or a dissipative transmission line and/or a controllable resistive component.

30

13.       The device of any of the claims 8 to 12, wherein the linear and/or the nonlinear branch-circuit have a filtering circuit at an output terminal.

14. The device of claim 8, wherein the phase control unit comprises at least one transmission line or at least one, controlled resistive element.
- 5 15. The device of any of the claims 8 to 12, wherein the circuit is integrated in a semiconductor device.

## ABSTRACT:

FRO - DG 1

22.10.2002

(71)

A method for a pre-distortion linearizing a branched signal for a RF amplifier, comprising supplying a branched signal to at least one input terminal (2); distributing a power of the input signal present on at least one input terminal (2) to a plurality of parallel  
5 branch-circuits (16, 18, 20) as branched signal by a power distributing circuit (4); controlling a phase parameter and an amplitude parameter of the branched signals by at least one nonlinear branch-circuit (18, 20); controlling a phase parameter and an amplitude parameter of the branched signals by at least one linear branch-circuit (16); combining output branched signals of at least one nonlinear branch circuit (18, 20) with the output branched signals of at  
10 least one linear branch circuit (16) by a power combining circuit (12); providing an output branched signal of the power combining circuit (12) on at least one output terminal (14). Furthermore, a circuit for a pre-distortion unit linearizing a signal for a RF amplifier and a layout of a pre-distortion linearizing a signal for a RF amplifier are disclosed.

15 Fig. 1

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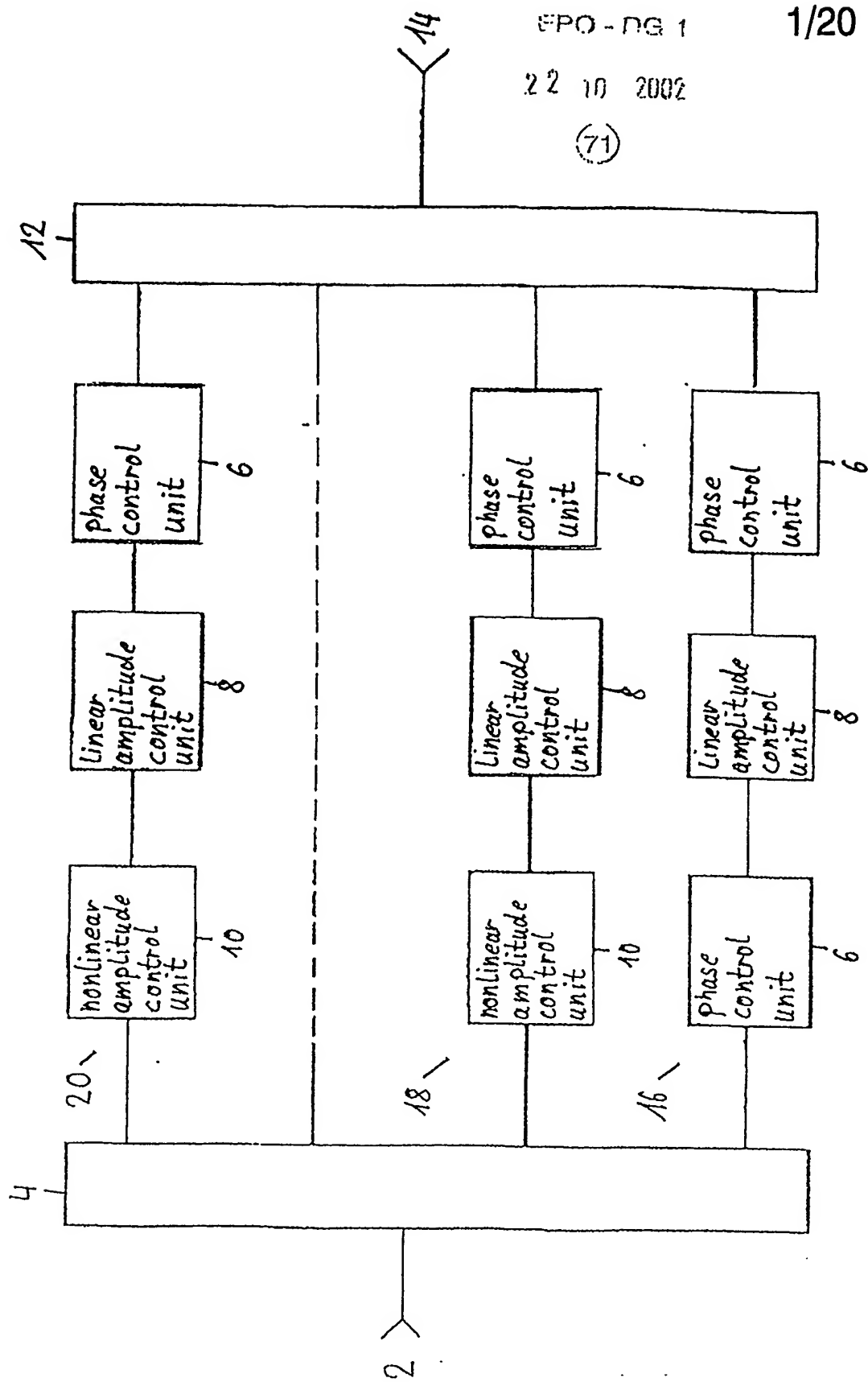


Fig. 1

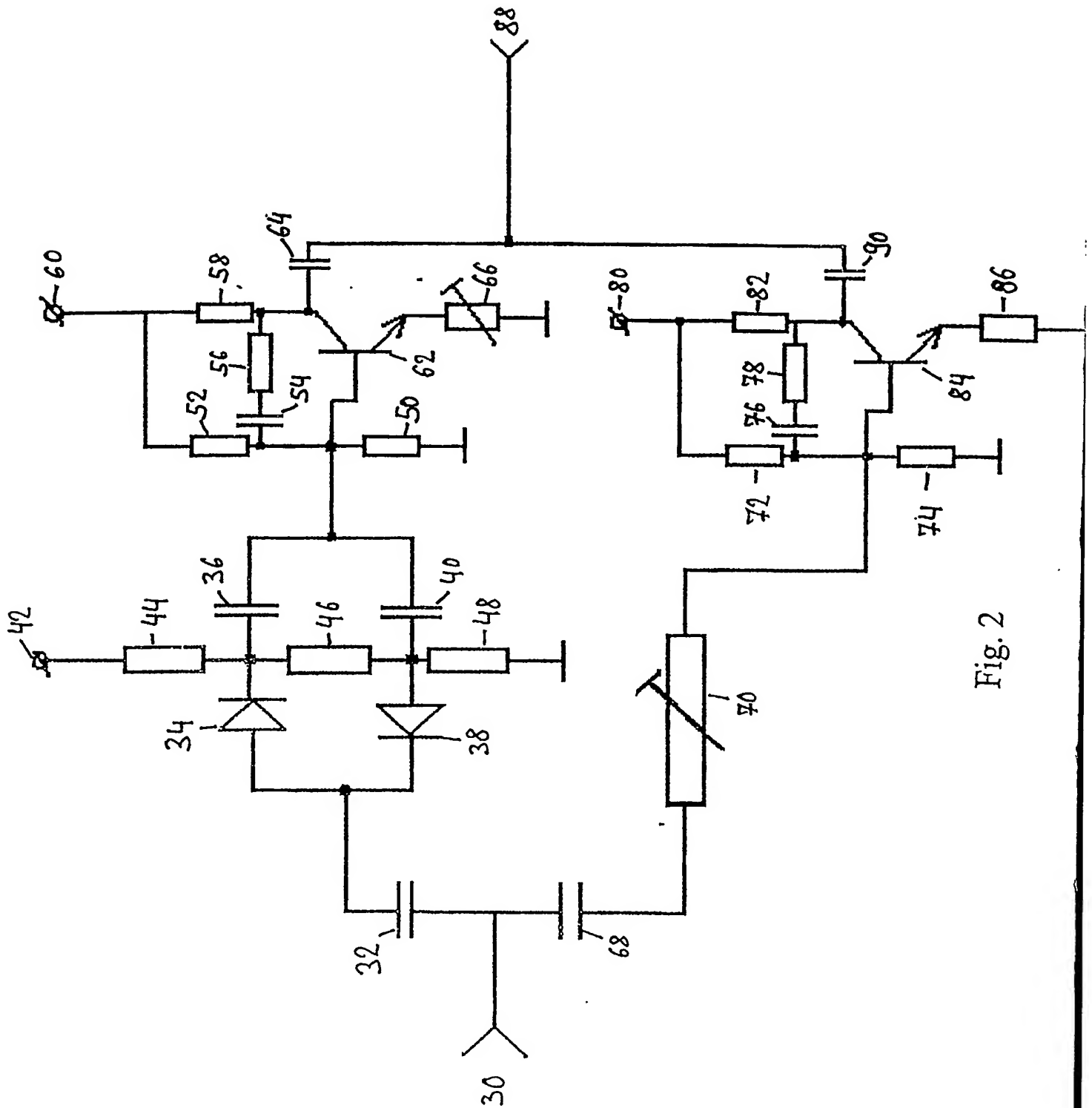


Fig. 2

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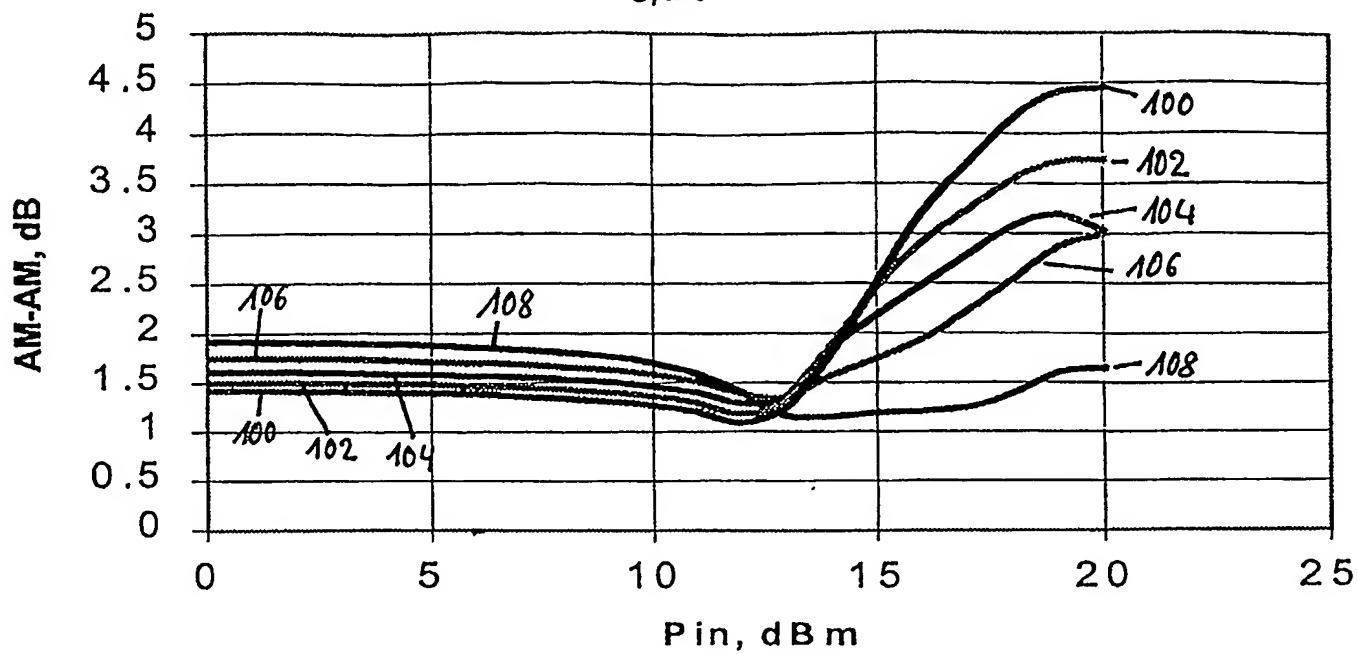


Fig. 3

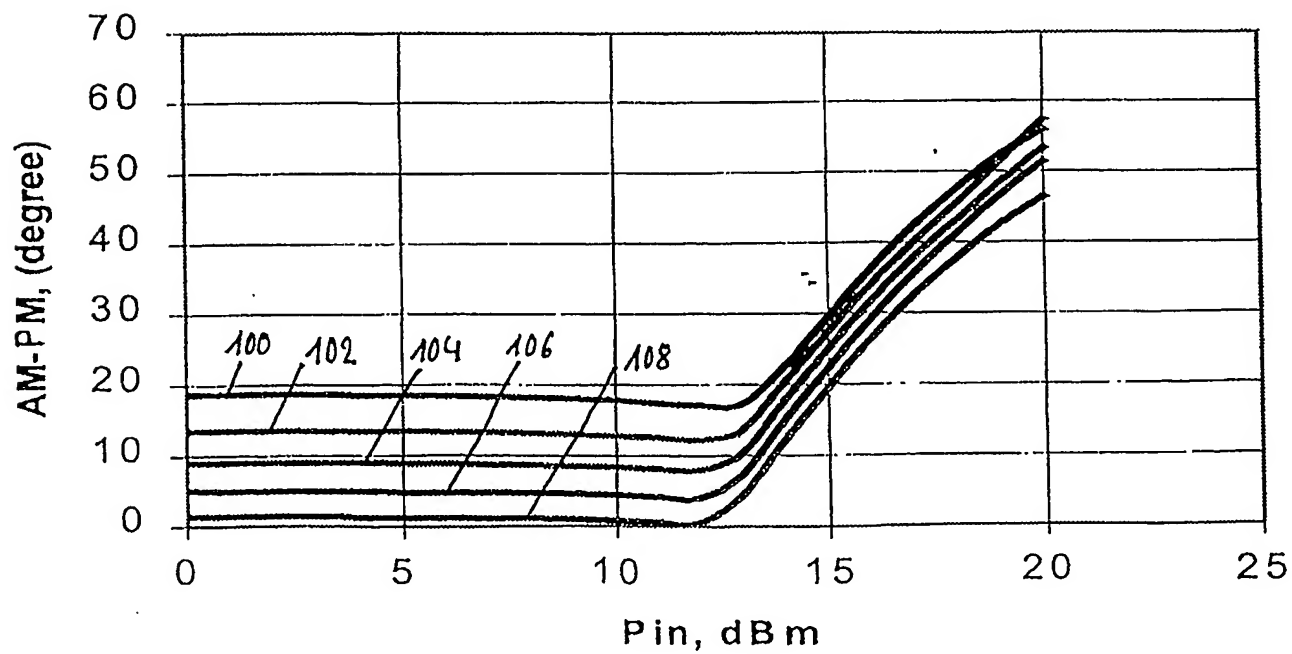


Fig. 4

4/20

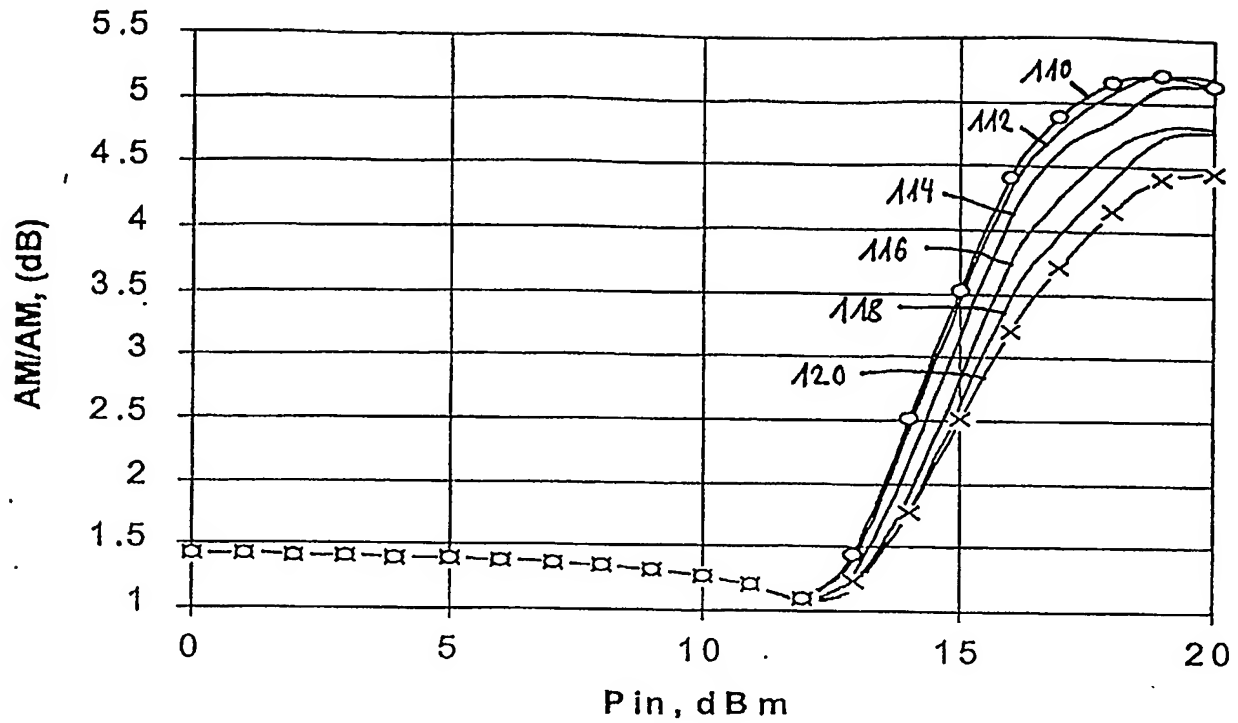


Fig. 5

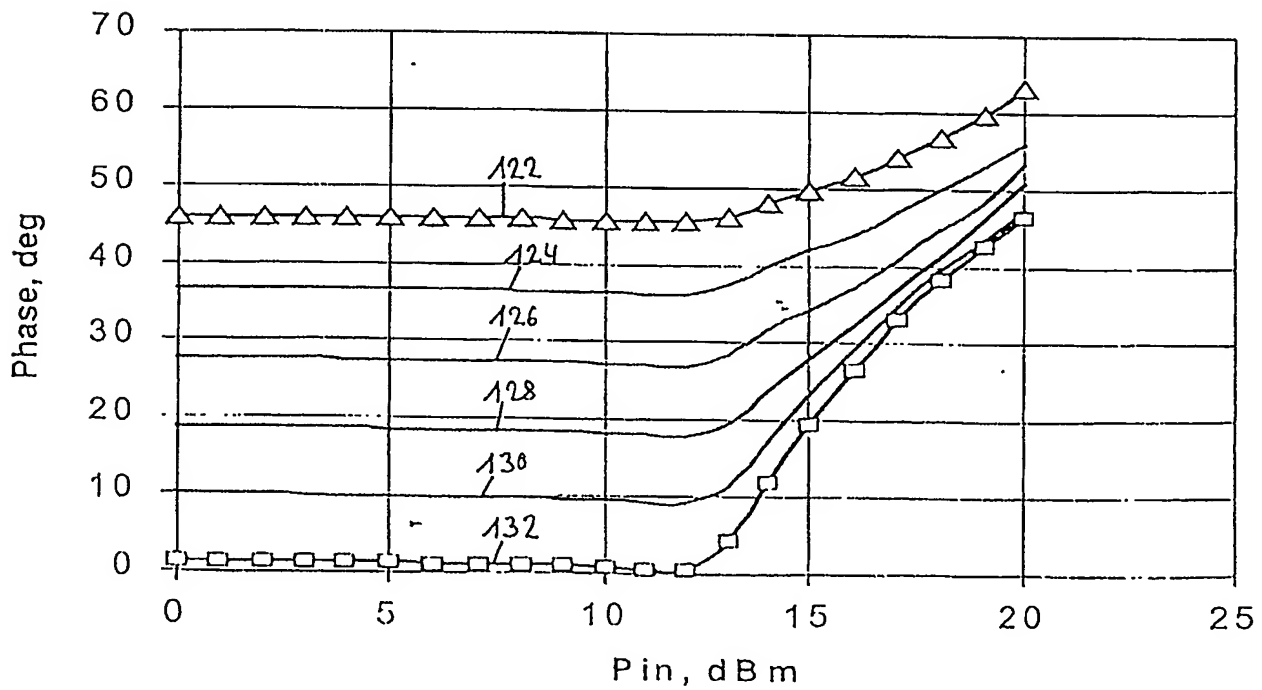


Fig. 6

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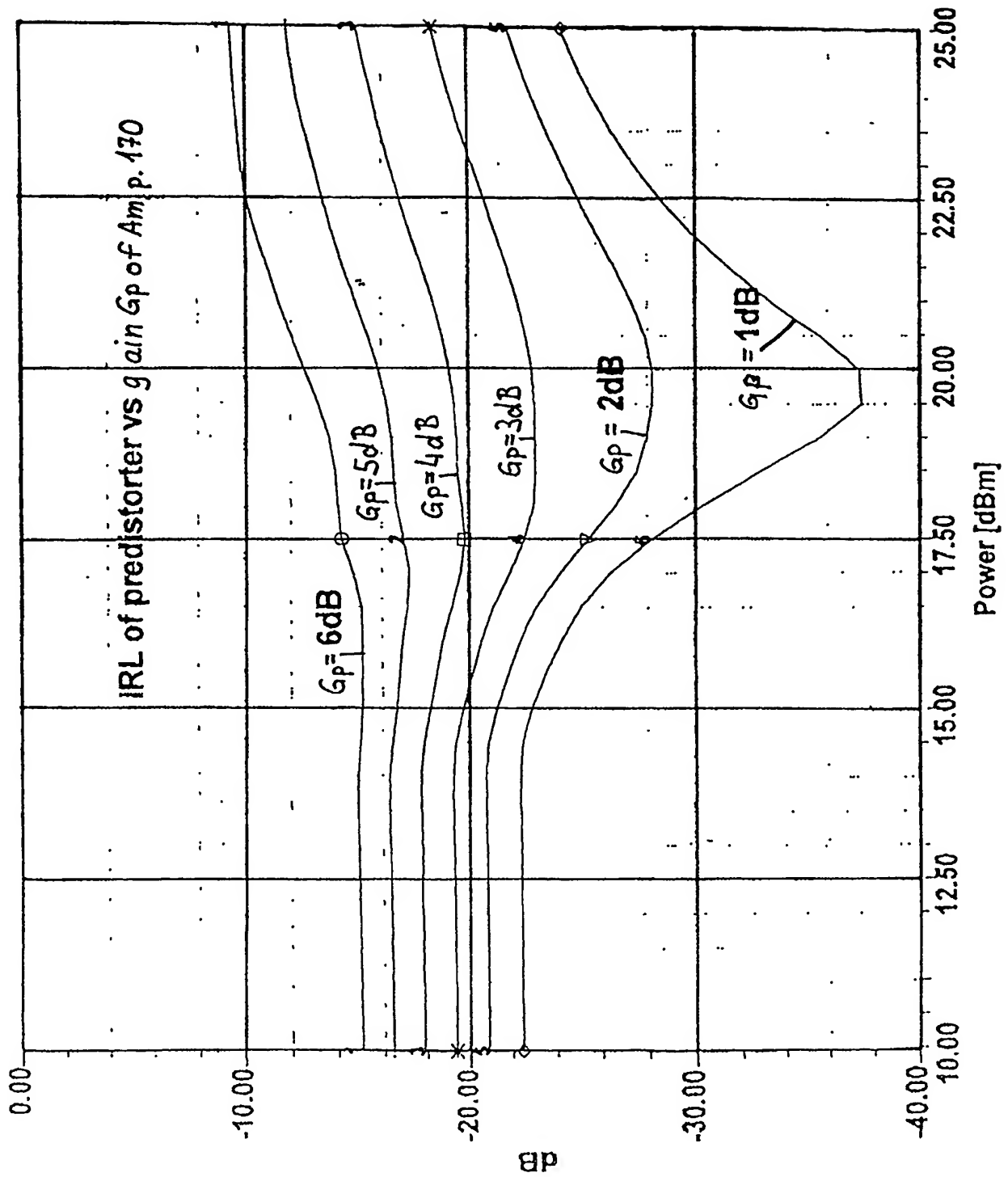


Fig. 16



6/20

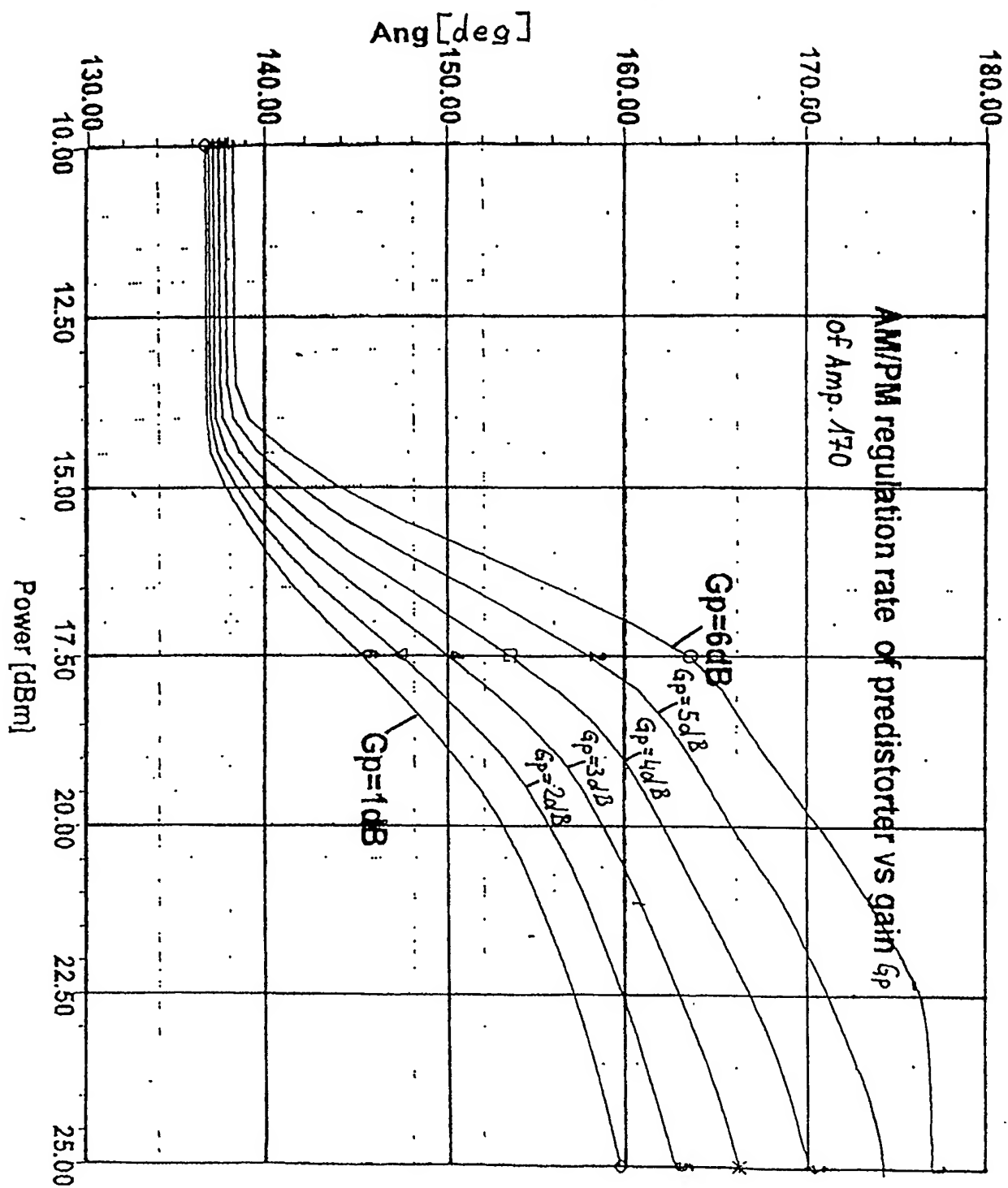


Fig. 15

7/20

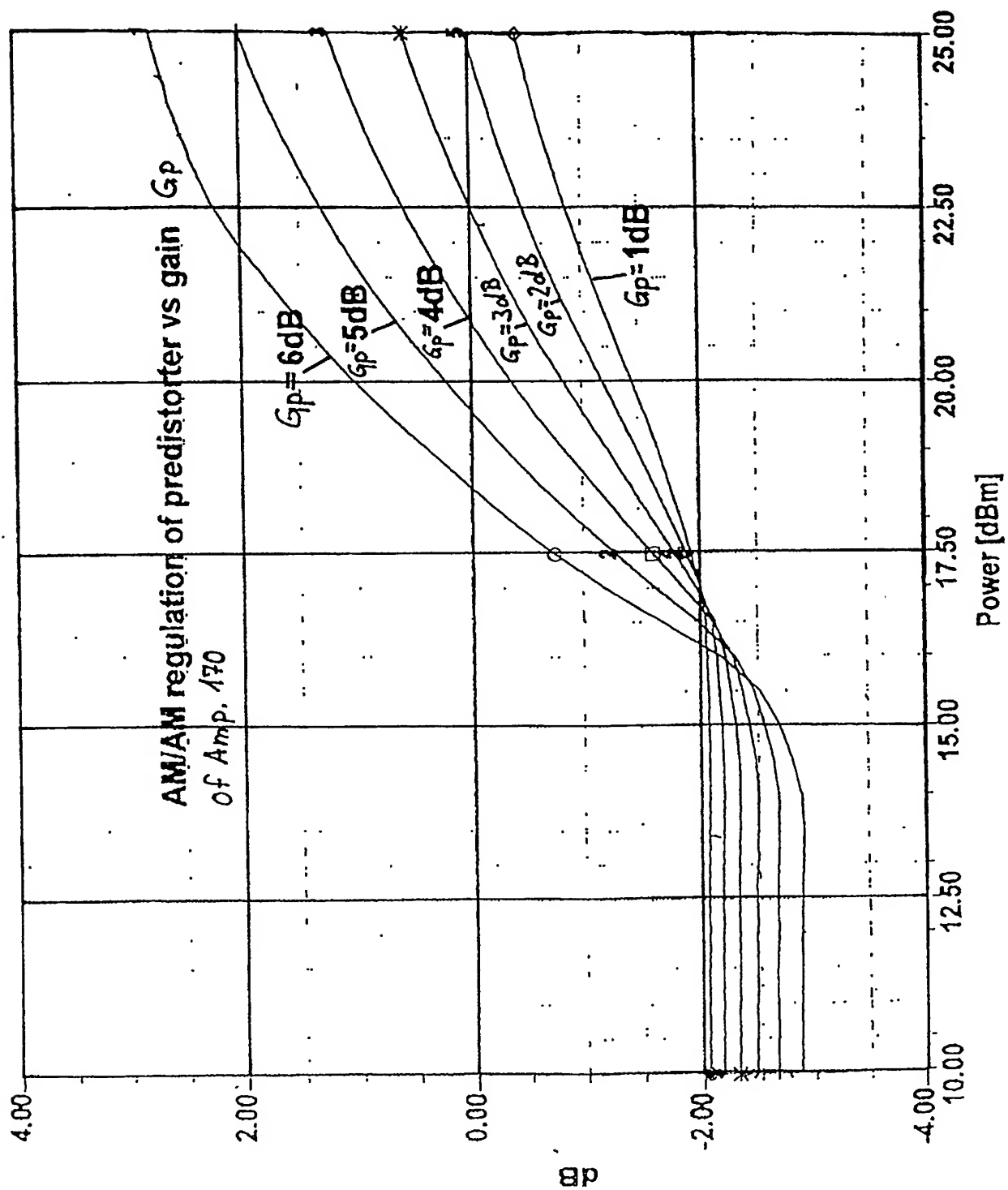


Fig. 14

8/20

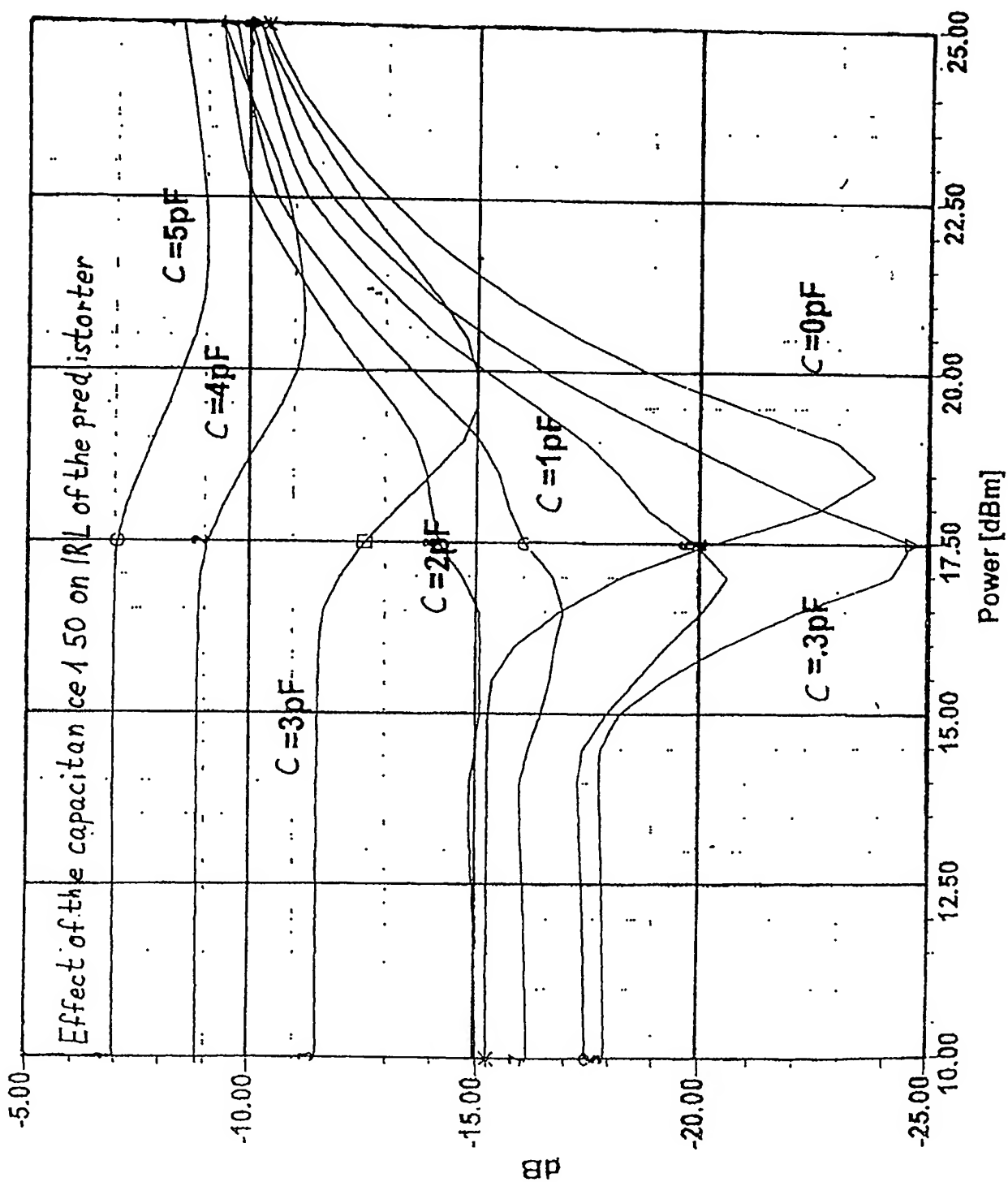


Fig. 13

9/20

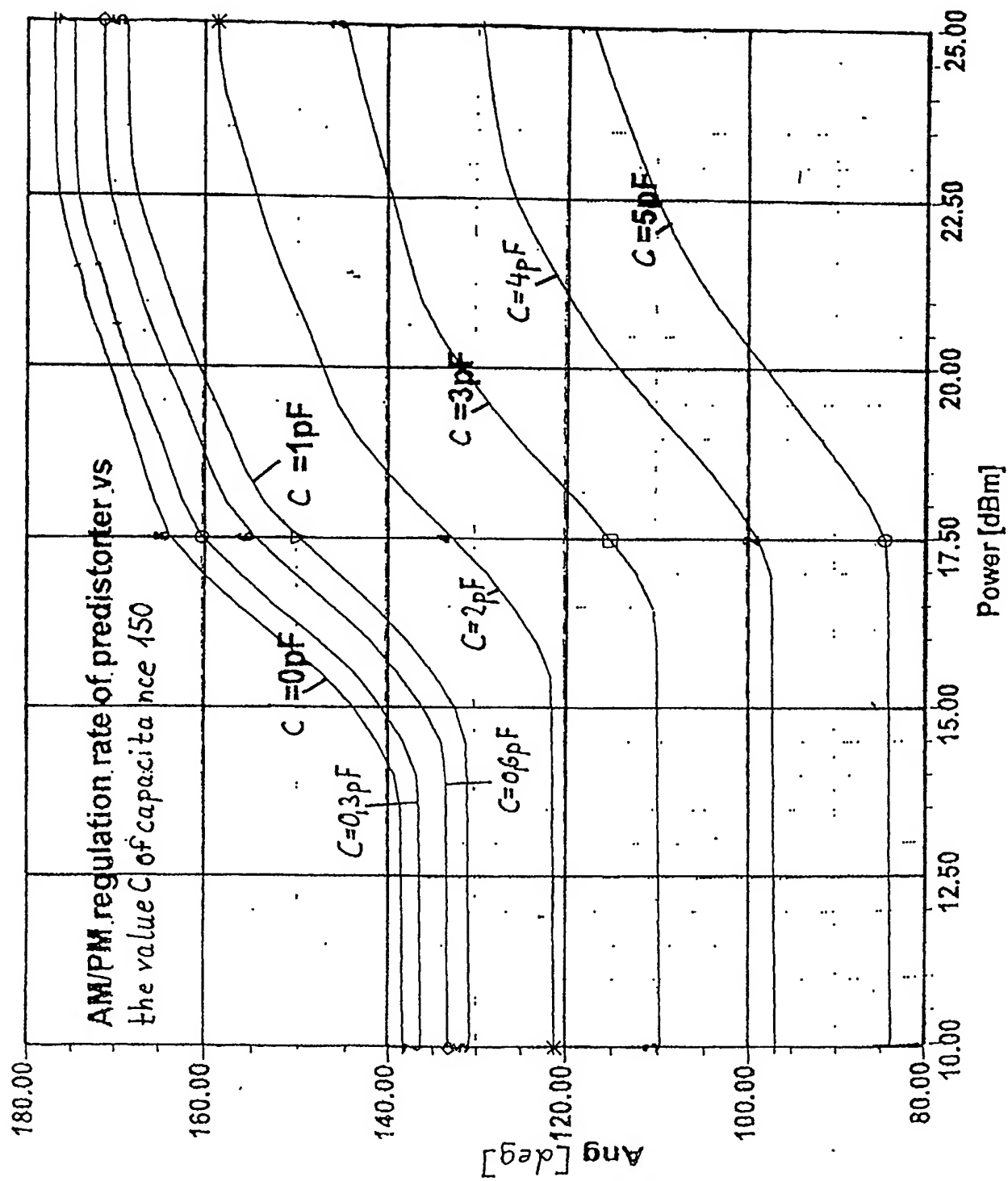


Fig. 12

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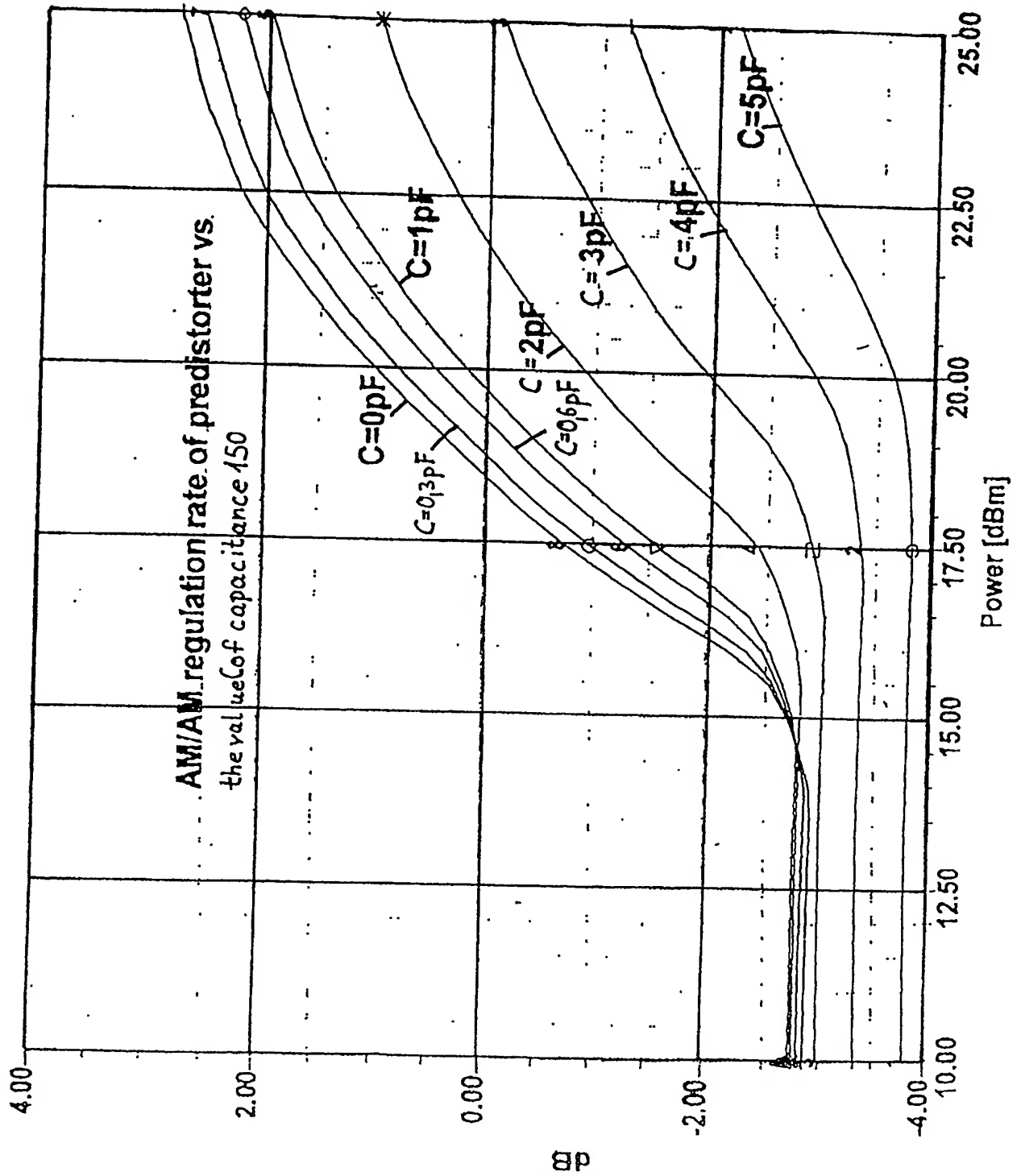


Fig.11

11/20

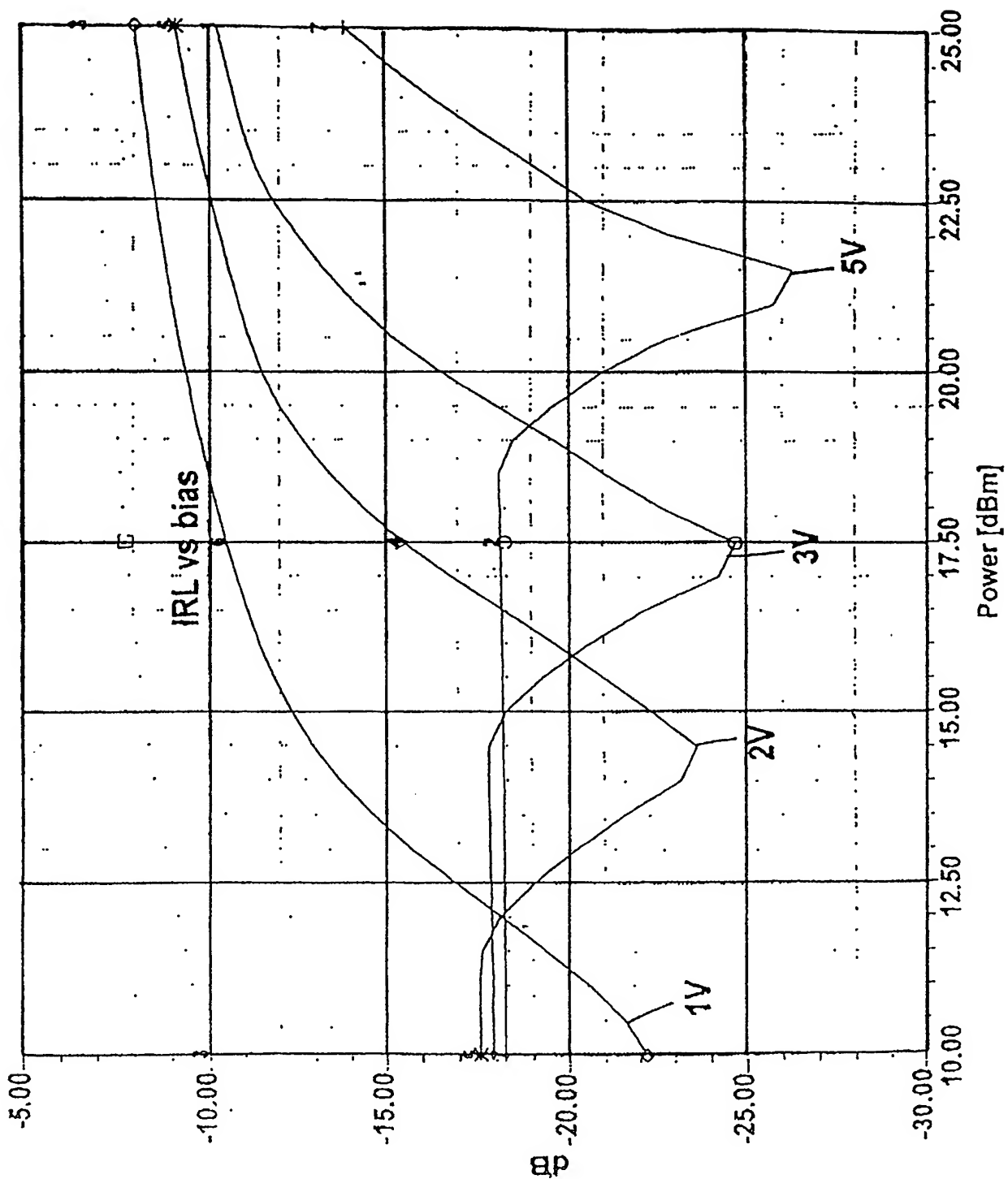


Fig. 10

12/20

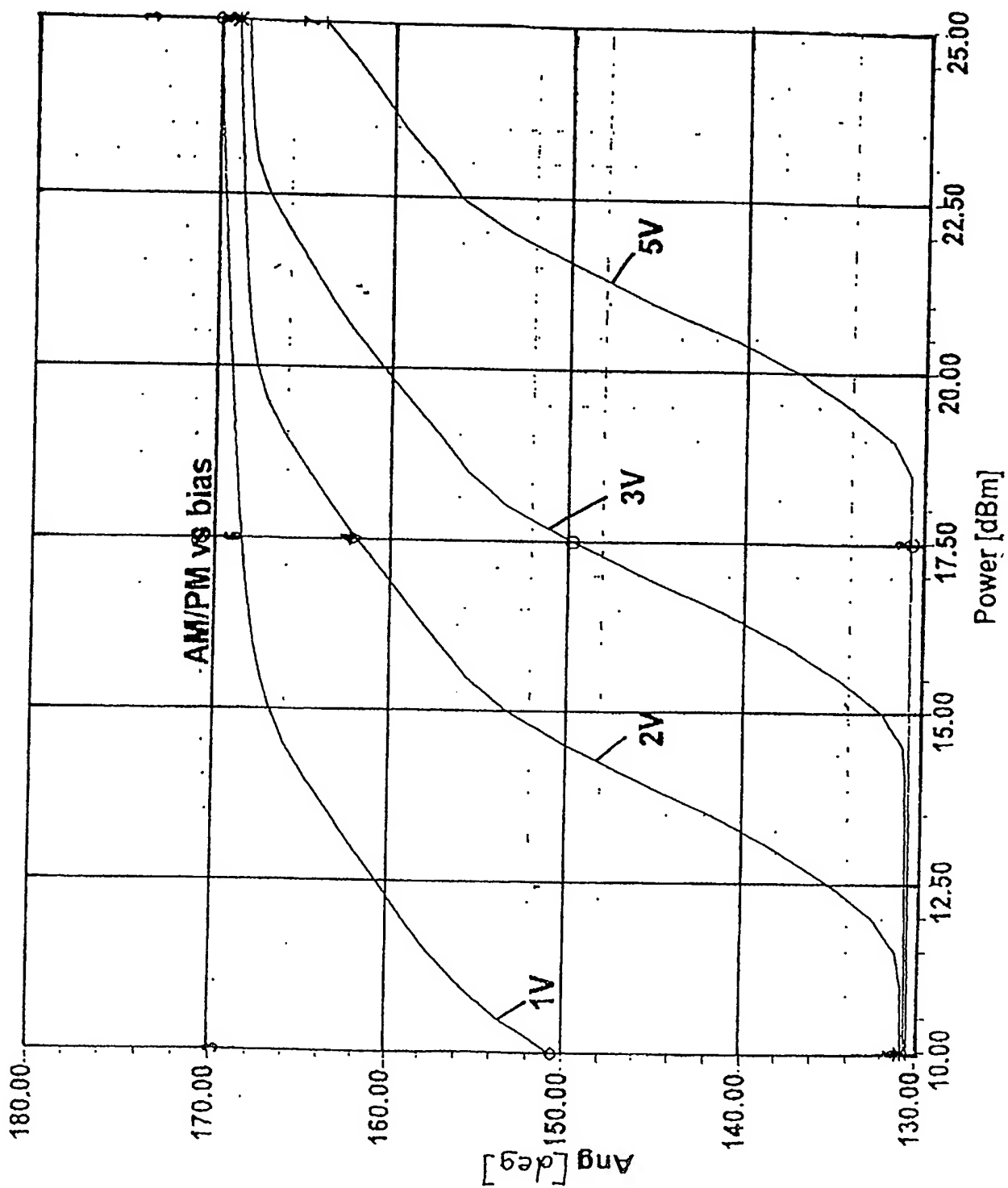


Fig 9

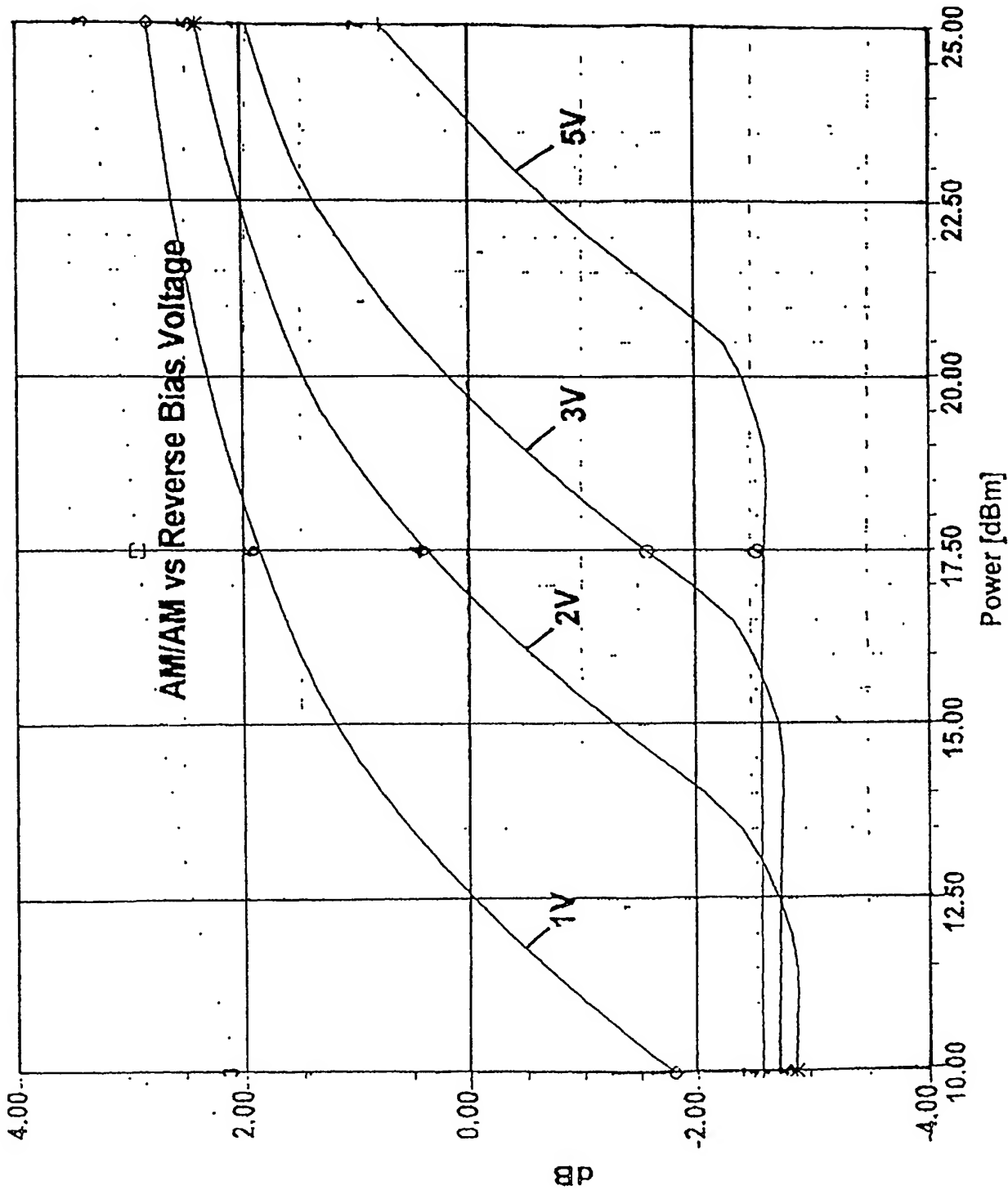


Fig. 8



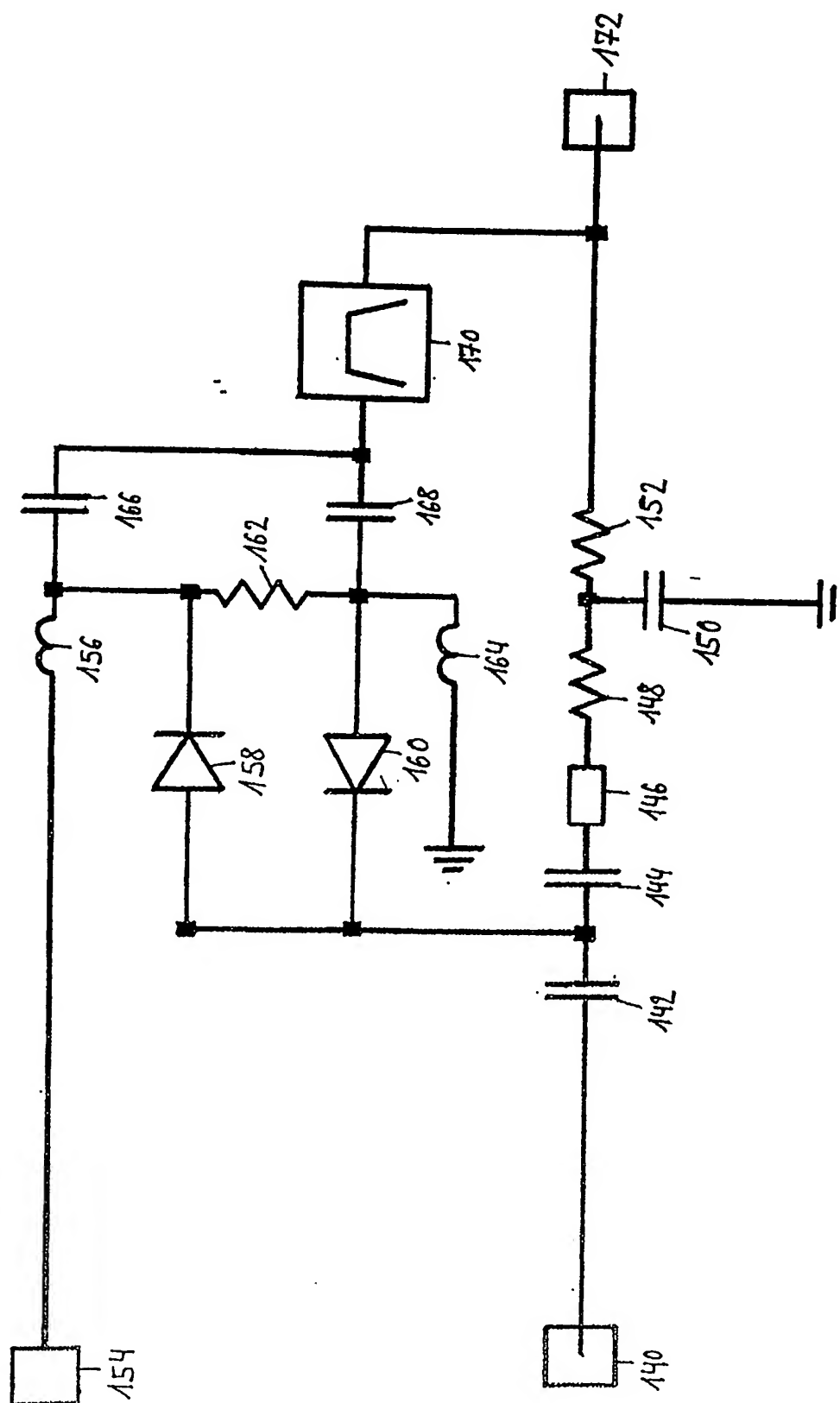


Fig. 7

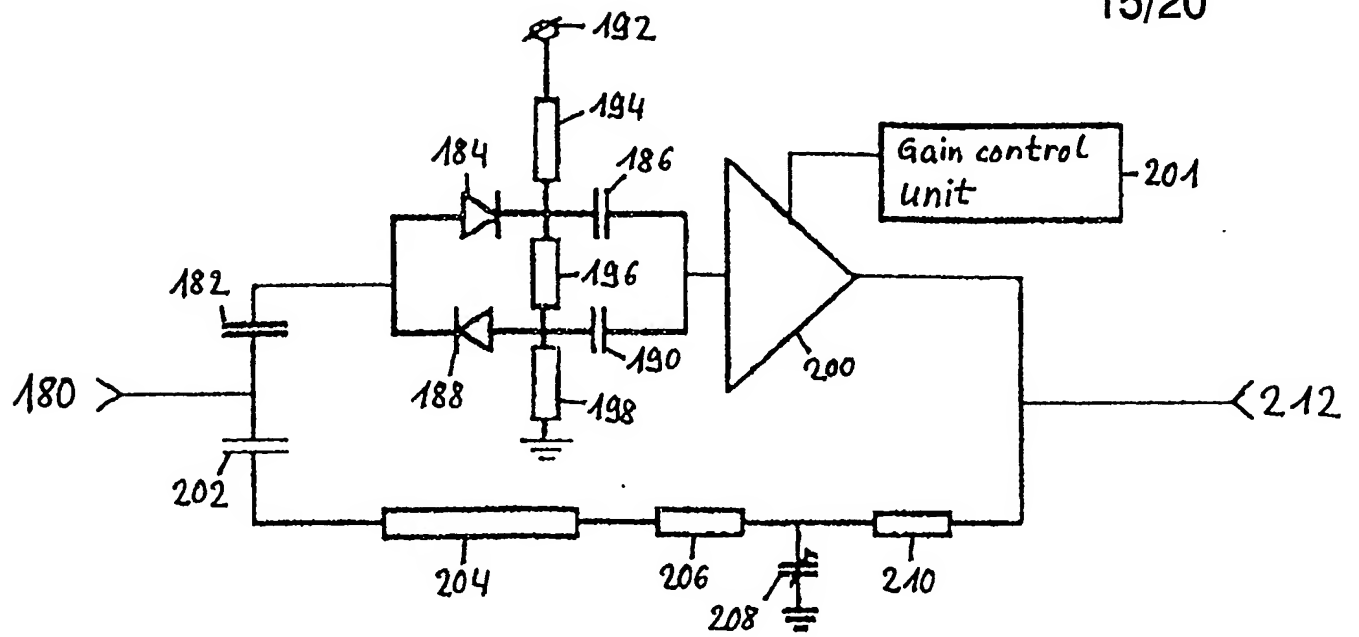


Fig. 17

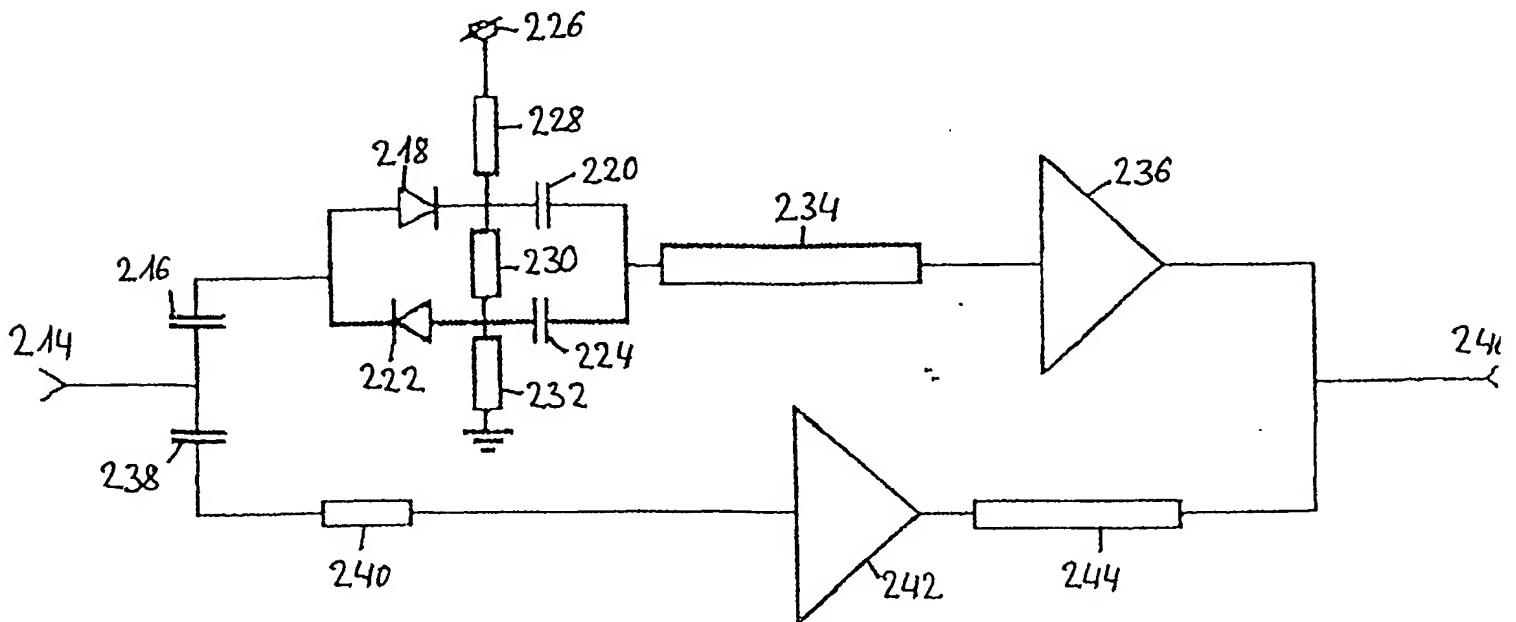


Fig. 18

16/20

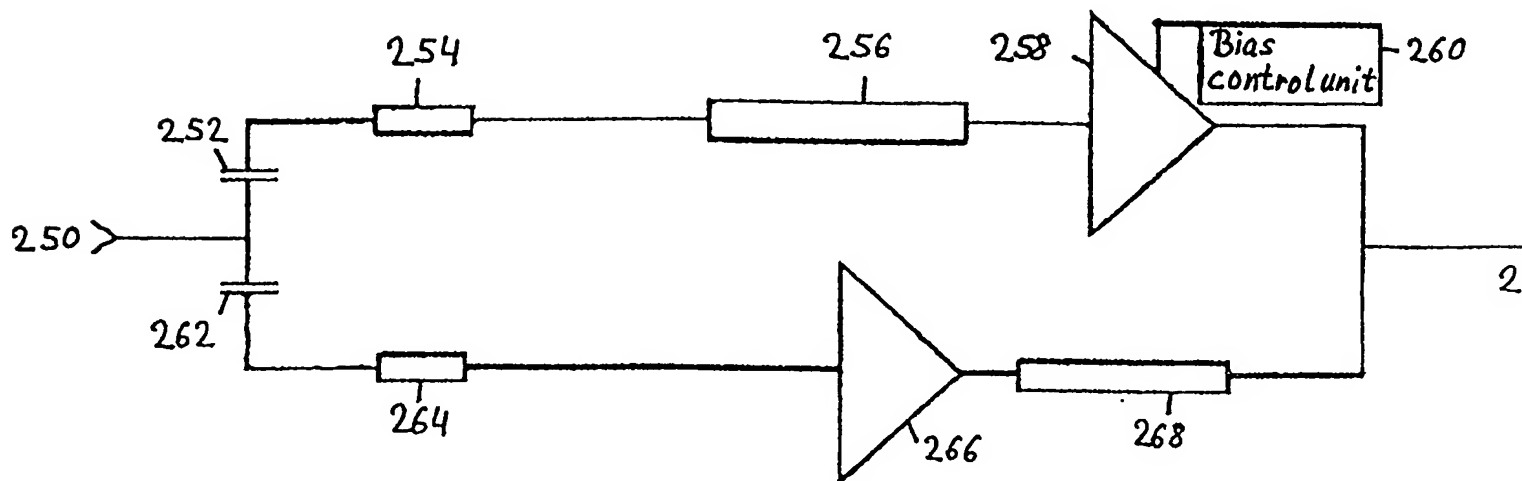


Fig. 19

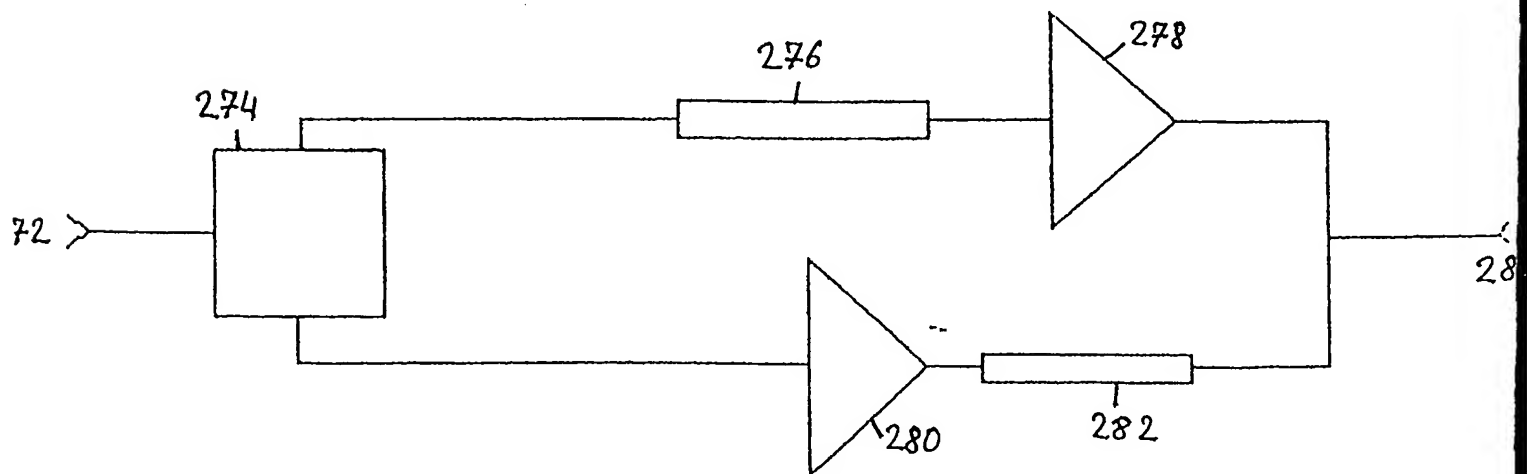


Fig. 20

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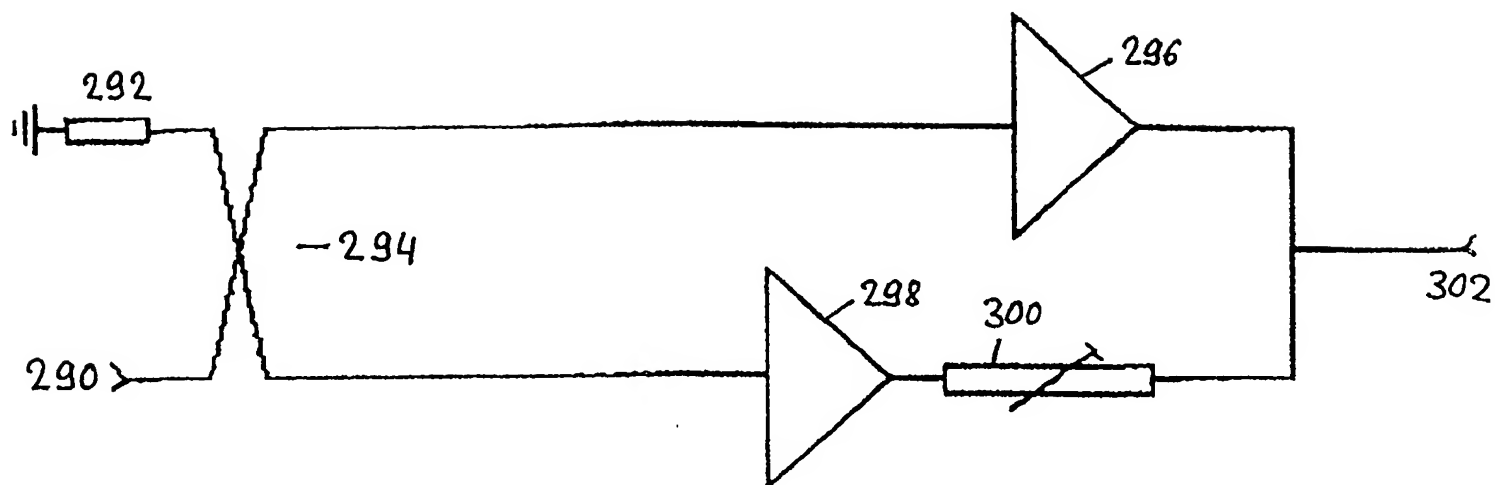


Fig. 21

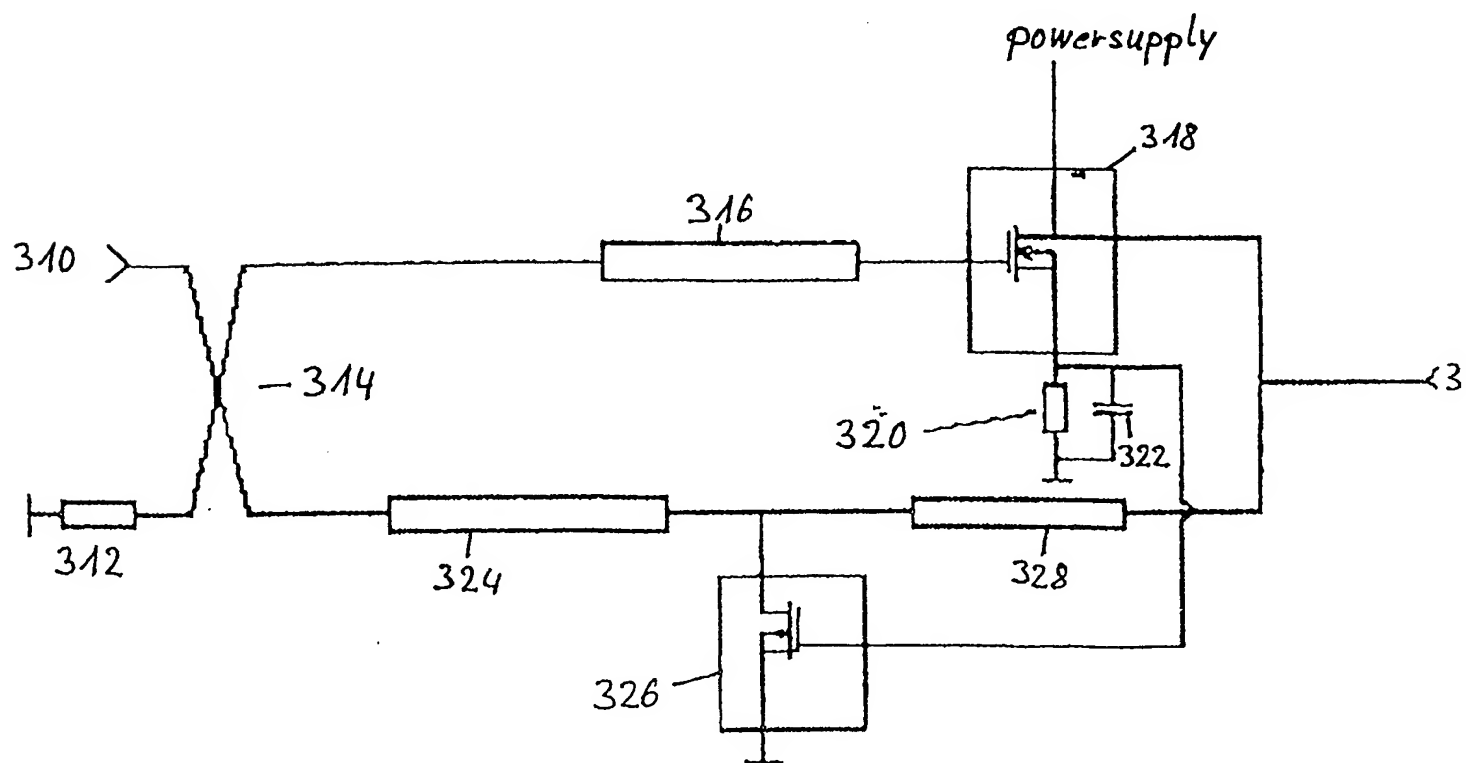


Fig. 22

18/20

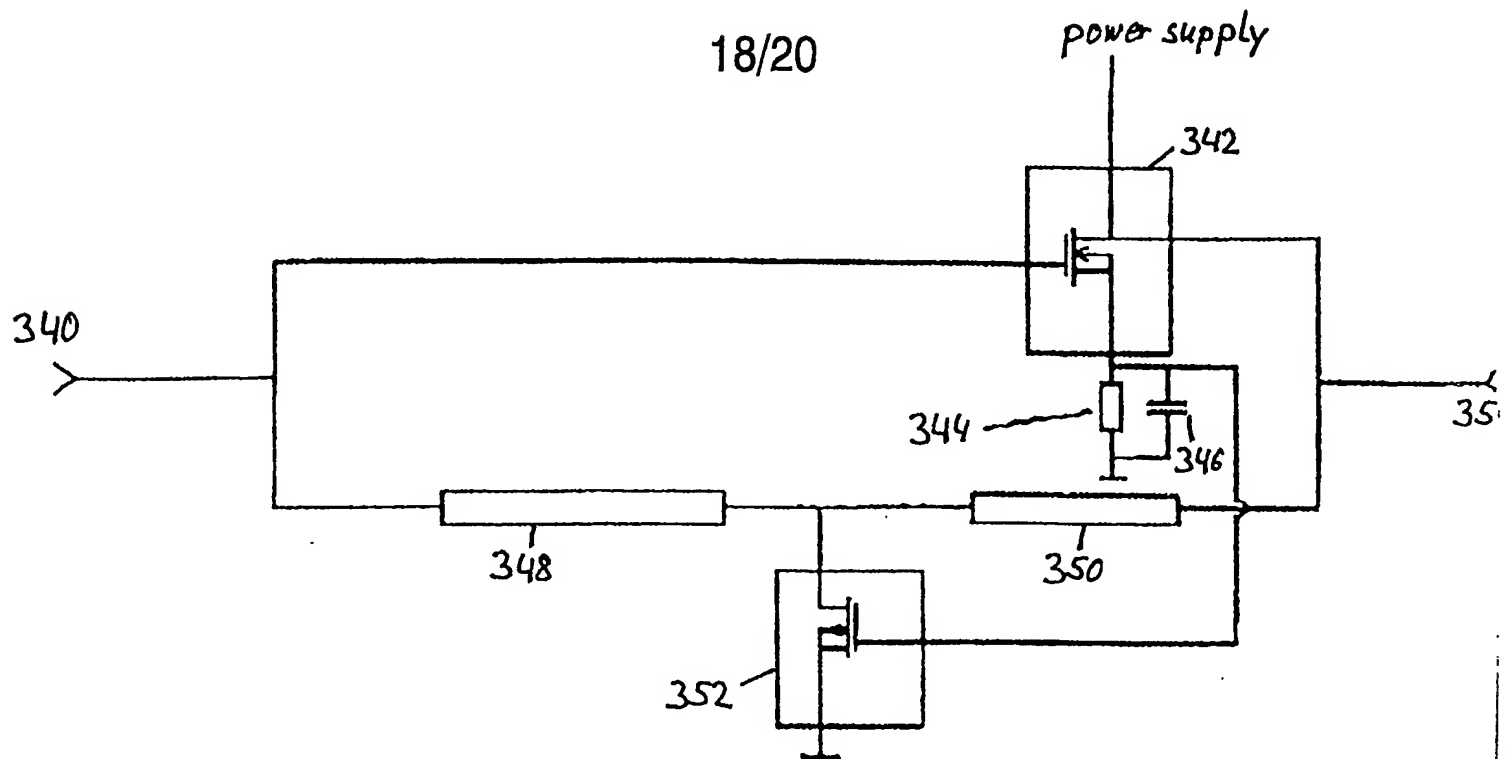


Fig. 23

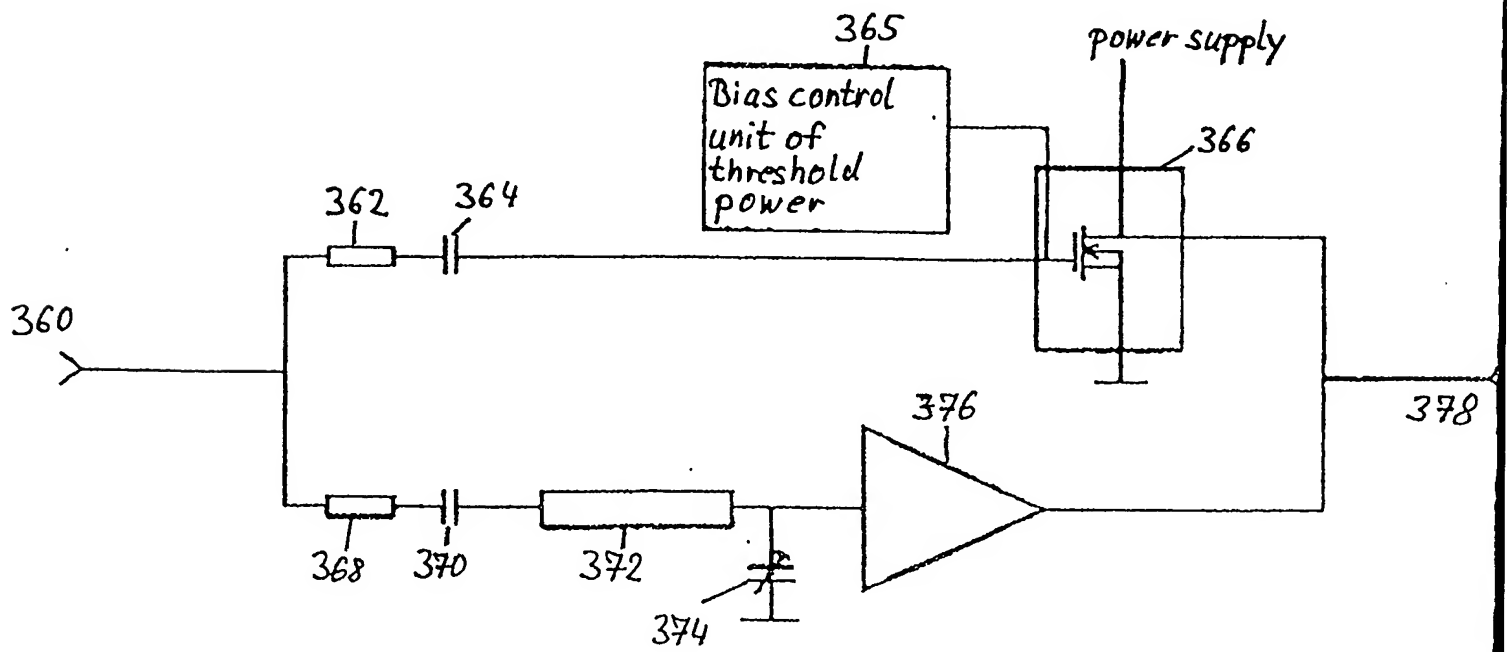


Fig. 24

19/20

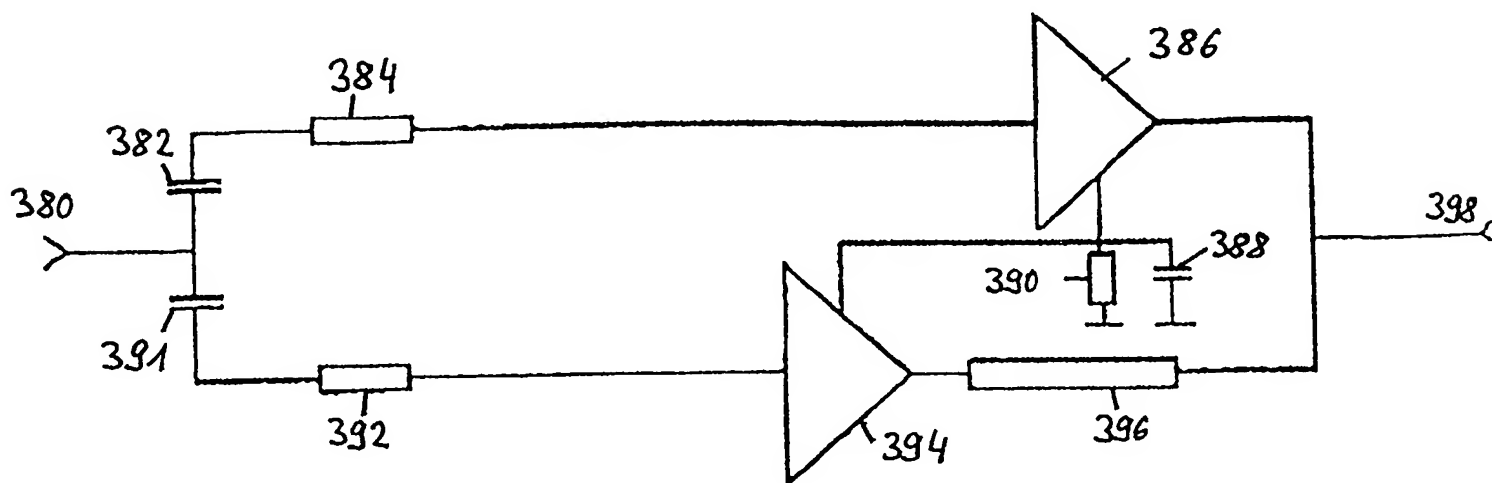


Fig. 25

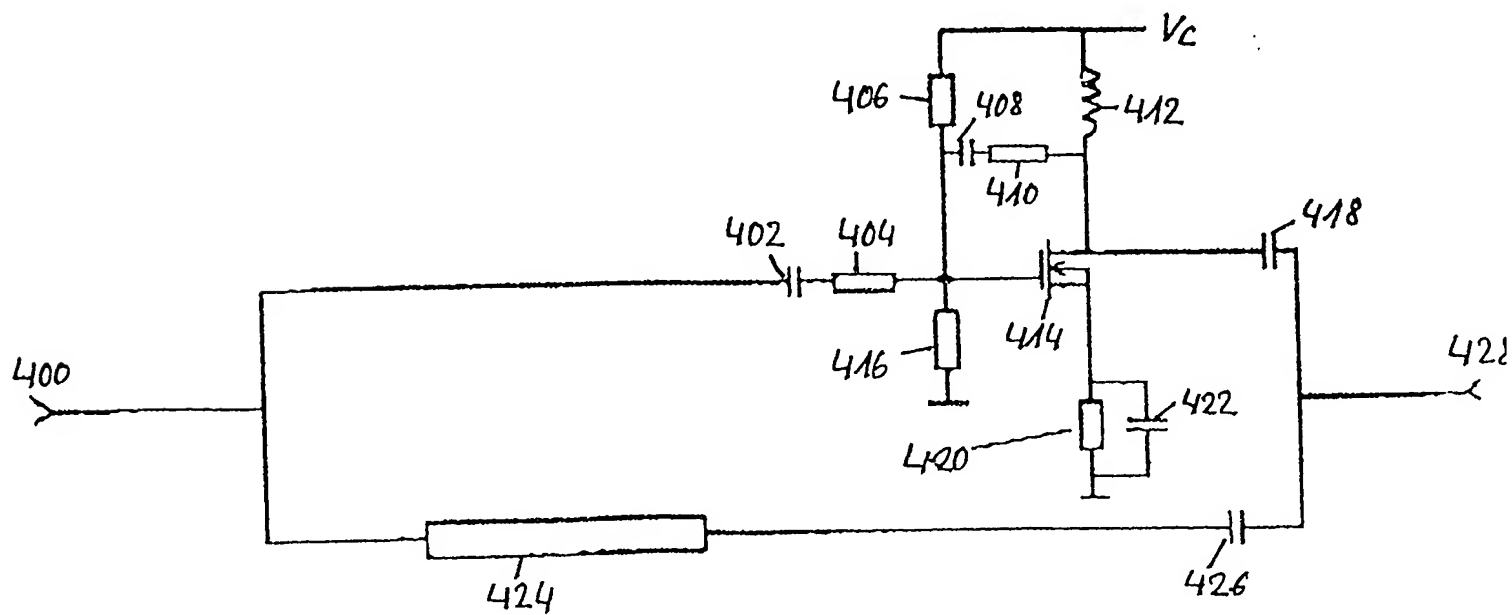


Fig. 26

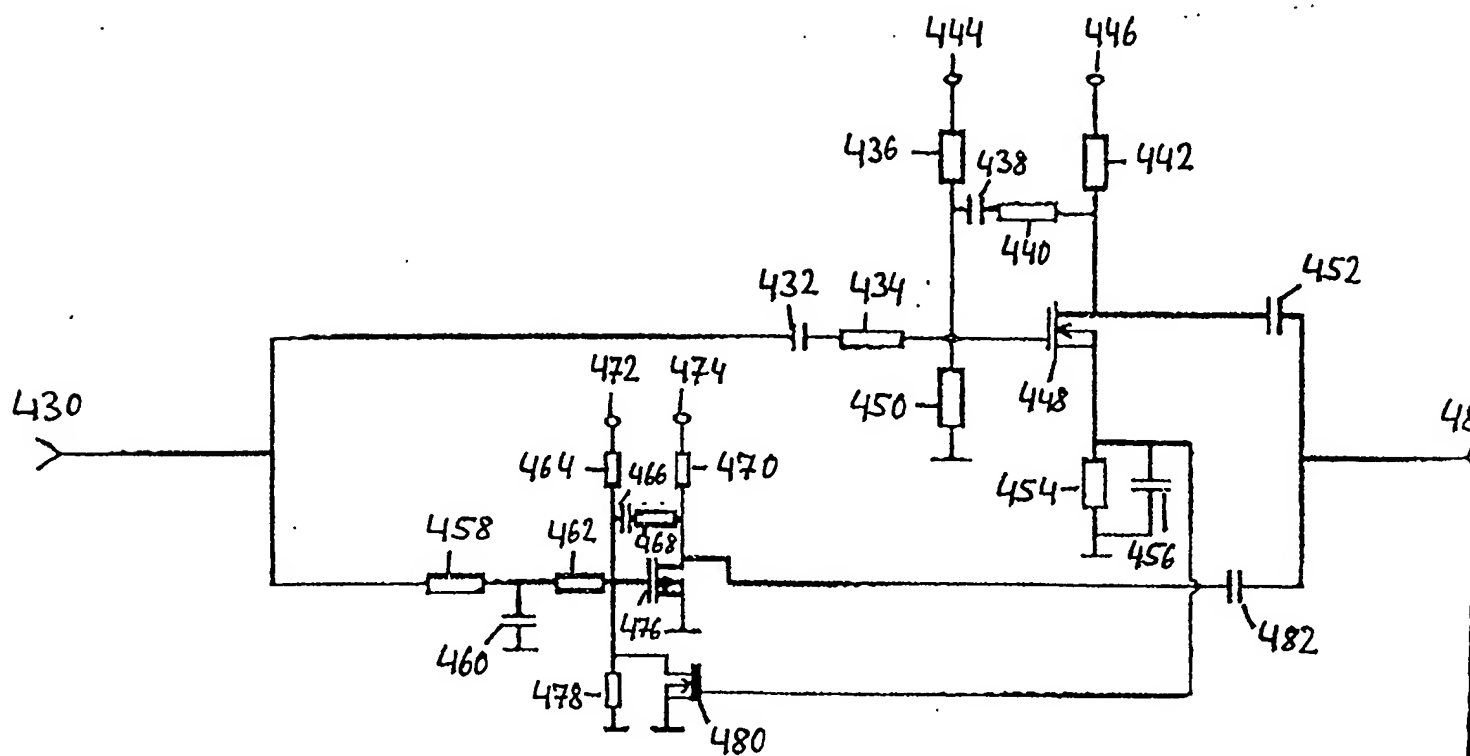


Fig. 27